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MULTIDETECTOR COMPUTED TOMOGRAPHY OF FACIAL TRAUMA

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ACADEMIC DISSERTATION

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To my family

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LIST OF ORIGINAL PUBLICATIONS

This thesis is based on the following original publications, referred to in the text by their

Roman numerals (I–V):

- I Salonen EM, Koivikko MP, Koskinen SK. Multidetector computed tomography imaging of facial trauma in accidental falls from heights. *Acta Radiologica* 2007; 48:449–455. doi:10.1080/02841850701199959
- II Salonen EM, Koivikko MP, Koskinen SK. Acute facial trauma in falling accidents: MDCT analysis of 500 patients. *Emergency Radiology* 2008; 15:241–247. doi:10.1007/s10140-008-0717-2
- III Salonen EM, Koivikko MP, Koskinen SK. Violence-related facial trauma: analysis of multidetector computed tomography findings of 727 patients. *Dentomaxillofacial Radiology* 2010; 39:107–112. doi:10.1259/dmfr/67015359
- IV Peltola EM, Koivikko MP, Koskinen SK. The spectrum of facial fractures in motor vehicle accidents: an MDCT study of 374 patients. *Emergency Radiology* 2014; 21:165–171. doi: 10.1007/s10140-013-1173-1
- V Peltola EM, Mäkelä T, Haapamäki V, Suomalainen A, Leikola J, Koskinen SK, Kortenesniemi M, Koivikko MP. CT of facial fracture fixation: an experimental study of artefact reducing methods. *Dentomaxillofacial Radiology* 2017; 46: 20160261. doi 10.1259/dmfr.20160261

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ABSTRACT

Facial fractures are a common problem worldwide. They are often caused by falls, falls from heights, motor vehicle accidents, and violence. In Studies I-IV, we retrieved all 2413 emergency room physicians' multidetector computed tomography (MDCT) requests for facial injury during a 62-month time period. These were categorized by etiology: 155 cases of fall-from-height accidents, 500 cases of falling accidents, 727 cases due to violence, and 374 cases following a motor vehicle accident. The fractures were divided into groups: nasal bone, orbital, naso-orbito-ethmoid, zygomatic complex, zygomatic arch, Le Fort I, II, and III, frontal bone, maxillary, mandibular, and skull base fractures. These were further classified into different subtypes. Paranasal sinus effusions were noted as well. In falls from heights, nasal bone and zygomatic arch fractures were seldom solitary fractures, but were indicators of a more severe fracture. In falls, the most common fracture is the zygomatic complex fracture, whereas in violence-related fractures nasal and orbital fractures predominated. In motor vehicle accidents, Le Fort, frontal bone, and zygomatic arch fractures were always accompanied by other fractures. We also found that a clear sinus sign is a valuable aid in detecting facial fractures, but it might be less reliable than previously thought. Le Fort fractures were often asymmetric or unilateral.

Postoperative maxillofacial imaging has earlier been somewhat challenging due to the artifacts caused by metal. In Study V, we compared different devices and protocols by scanning a phantom with a 64-slice computed tomography, cone-beam computed tomography, and a high-definition multislice computed tomography with dual-energy scan and iterative reconstruction methods. For postoperative maxillofacial imaging, cone-beam computed tomography was not optimal. Multidetector computed tomography with adaptive statistical iterative reconstruction offers fast image volume reconstruction with good image quality.

ABBREVIATIONS

2D	Two-dimensional
3D	Three-dimensional
AP/PA	anteroposterior/posteroanterior
ASiR	Adaptive statistical iterative reconstruction
ATLS	Advanced trauma life support
CBCT	Cone-beam computed tomography
CSS	Clear sinus sign
CT	Computed tomography
ED	Emergency department
FAST	Focused assessment with sonography for trauma
FBP	Filtered back projection
FFH	Falls from heights
FOV	Field of view
GCS	Glasgow Coma Scale
GSI	Gemstone spectral imaging
IR	Iterative reconstruction
LF I-III	Le Fort I-III
MBIR	Model-based iterative reconstruction
MDCT	Multidetector computed tomography
MPR	Multiplanar reformation
MRI	Magnetic resonance imaging
MSCT	Multislice computed tomography
MVA	Motor vehicle accident
NOE	Naso-orbito-ethmoid
ORIF	Open reduction internal fixation
PACS	Picture archiving and communication system
PET	Positron emission tomography
ROI	Region of interest
US	Ultrasound
VCT	Volume computed tomography
VEO	Model-based iterative reconstruction technique
ZMC	Zygomatico-maxillary complex (also known as zygomatic complex)

INTRODUCTION

The face is very important to humans. We need it to see, to breathe, to eat, to smell, to talk, and to communicate without words, with nuances reflected in our expression. Esthetics also cannot be disregarded in the world in which we live today.

Injury to the face can result in damaging one or more of these functions, with effects ranging from a minor nuisance to life-threatening complications. Quality of life can be at stake (Conforte et al. 2016).

Surgery has a long history, dating back to ancient Egypt and Greece, and even earlier cultures (Forsius 2010). Traumatology has been suggested to be one of the first forms of medicine (Salo 2010). Modern traumatology took its first steps in the 16th to 18th centuries, as understanding of wound healing and ventilation grew (Salo 2010).

A major step in diagnosing fractures occurred in the late 19th century, when Wilhelm Röntgen discovered the x-rays in 1895. For the first 50 years, plain radiography and contrast-enhanced radiography were the basis of imaging. In 1972, the first computed tomography (CT) scanner was introduced. In 1979, the Nobel Prize in medicine was awarded to Sir Godfrey N. Hounsfield and Alan M. Cormack for the development of computer-assisted tomography (Mahesh 2009). Single-section helical computed tomography was taken into use in 1988. In 1992, the first multidetector computed tomography (MDCT) scanner, a dual-section helical scanner, was introduced. In 1998, the four-detector scanner was launched (Rydberg et al. 2000), followed later by 8- and 16-detector scanners. Currently, 64-detector helical CT units are widespread (Geijer and El-Khoury 2006), and even 320-detector row CT exists (Choi et al. 2016). Cone-beam computed tomography (CBCT), by contrast, has been in commercial use for almost 20 years (Pogrel 2014). However, the first-generation CBCT was already used in 1982 (Luminati and Tagliafico 2014). Further, magnetic resonance imaging (MRI) has widely been used for about 30 years. MRI was co-invented by Paul C. Lauterbur and Sir Peter Mansfield, who shared the Nobel Prize in Medicine in 2003 for their accomplishments (www.nobelprize.org).

In the last 50 years, technology has evolved enormously: in addition to MDCT, CBCT, and MRI, such modalities as ultrasound (US) and positron emission

tomography (PET) have been introduced (Chen and Whitlow 2011). All of these are now a remarkable aid in diagnostics.

Trauma care in general has also improved greatly, resulting in more severely injured patients reaching trauma centers and surviving. In the early days, there were inadequate means to treat facial fractures; the target then was the prevention of infection and restoration of occlusion (Bredell and Grätz 2011). Managing these injuries during wartime gave experience and helped to create the protocols used today (Bredell and Grätz 2011, Bagheri et al. 2012). After the development of screws and plates, restoration of the complex facial structure was finally possible (Bredell and Grätz 2011).

REVIEW OF THE LITERATURE

Anatomy of the face

The skull is a bony structure supporting the face and protecting the brain. The skull bones can be divided into two groups: those of the cranium and those of the face. The cranium is made up the calvarium (skullcap) and the skull base. The calvarium comprises frontal, occipital, and parietal bones. The base of the skull is made up of frontal, sphenoid, ethmoid, occipital, parietal, and temporal bones.

The anatomical structure of the face is very complex, consisting of various bones and muscles. The frontal bone comprises the superior part and the mandible the inferior part of the facial skeleton. The middle face consists of the maxillae, palatine bones, zygomatic bones, nasal bones, inferior nasal conchae, lacrimal bones, vomer, ethmoid bones (including superior and middle conchae), temporal bones (zygomatic processes), and the pterygoid plates of sphenoid bones.

Surgeons are interested in the four paired buttresses of the face. These are areas where the bone thickness is relatively increased and they support the functional units of the face: the eyes, muscles, airway, and occlusion. The buttresses either directly or indirectly interface with the cranium or skull base as a firm reference. The buttresses also define the form of face (Hopper et al. 2006); the soft tissues of the face are supported by the facial skeleton. Individual appearance is largely determined by minor differences in facial bone (Prendergast 2013).

There are four pairs of air-filled spaces within the skull and face; these paranasal sinuses are the maxillary, frontal, ethmoid, and sphenoid sinuses (Márquez et al. 2014). The largest by volume are the maxillary sinuses (Kapakin 2016). There is individual variation within these complex structures (Reddy and Dev 2012, Değermenci et al. 2016).

The facial anatomy also consists of various muscles, arteries and veins, nerves, and salivary glands. Regarding these, there are important points to assess with facial fractures. The masseter muscle is a strong muscle that can pull the fractured zygoma in a rotational deformity. With orbital fractures, the radiologist should note whether the medial rectus muscle is entrapped, whether the optic nerve is impinged, or whether there is a retrobulbar hematoma (Hopper et al. 2006).

Facial injuries

Facial trauma can result in injuries to the facial bones and soft tissues. These can also be accompanied by other related injuries.

Types of fractures

The fracture patterns depend on the surface and site of contact, the force, the direction of the force, and the resistance to the force (Bredell and Grätz 2011).

Facial fractures are typically categorized by anatomy. Facial fractures can be divided into frontal bone, orbital, zygomatico-maxillary complex (ZMC), zygomatic arch, naso-orbito-ethmoidal (NOE), nasal, Le Fort I (LF I), Le Fort II (LF II), and Le Fort III (LF III) fractures. Other facial fracture types are ones of the maxillary sinus wall and maxillary alveolar process, palate, and mandible (Andersson 2014). Skull base fractures are also included in craniofacial trauma (Bredell and Grätz 2011) (Figures 1a and 1b).

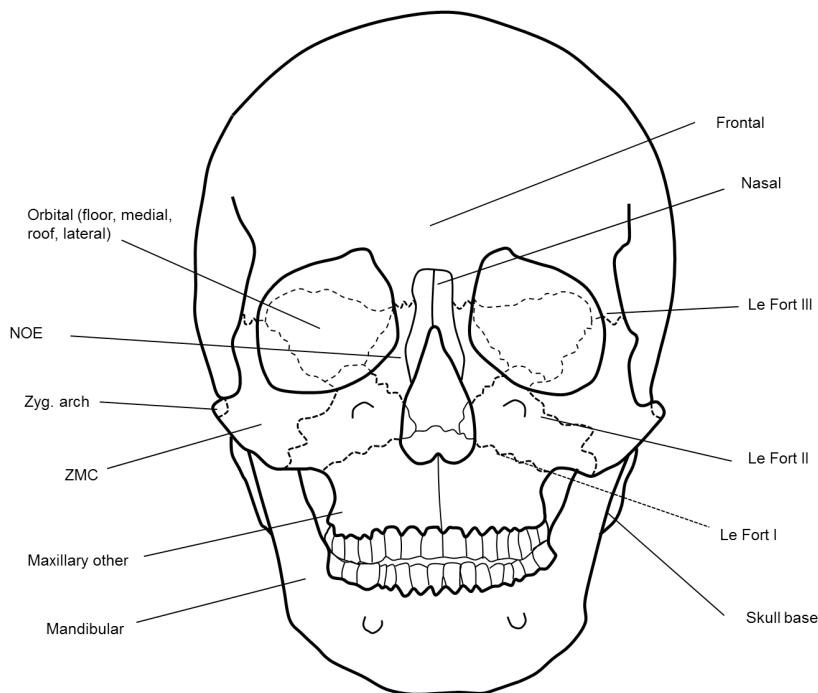


Fig. 1a. Categorization of facial fractures. *Reprinted and adapted with permission from Salonen EM, Koivikko MP, Koskinen SK. Acute facial trauma in falling accidents: MDCT analysis of 500 patients. Emergency Radiology 2008; 15:241–247. doi:10.1007/s10140-008-0717-2*

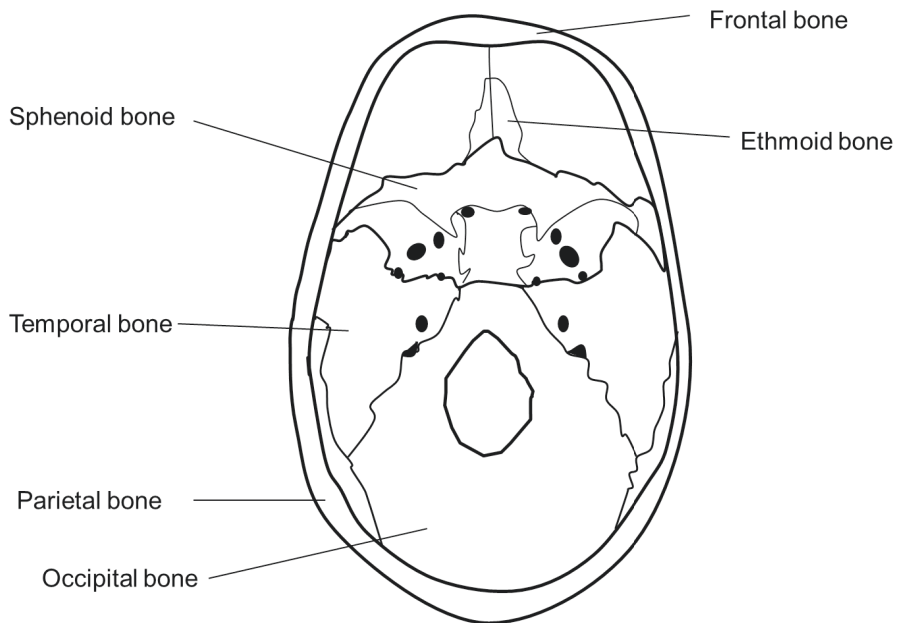


Fig.1b. Anatomy of the skull base, superior view.

Further, the mandible fractures can be subdivided into symphysis, parasymphysis, body, angle, ramus, condylar process, coronoid process, and alveolar fractures (Andersson 2014). Subcondylar fractures can also be included (Buch et al. 2016) (Figure 2). Mandible fractures are often bilateral (Lindqvist 2010, Andersson 2014), and usually two or more fractures are present (Bredell and Grätz 2011).

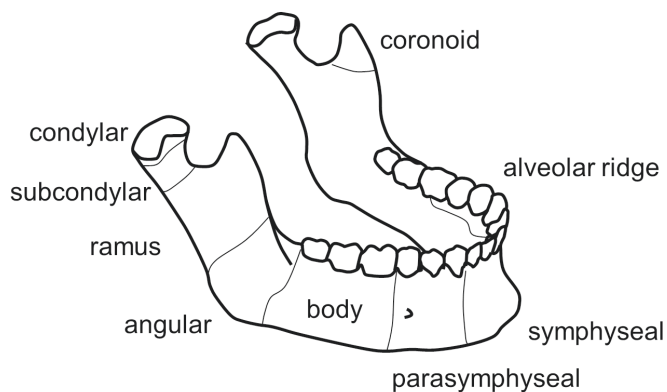


Fig. 2. Categorization of mandibular fracture areas. *Reprinted and adapted with permission from Salonen EM, Koivikko MP, Koskinen SK. Multidetector computed tomography imaging of facial trauma in accidental falls from heights. Acta Radiologica 2007; 48:449–455. doi:10.1080/02841850701199959*

There are differences in craniofacial injuries of children and adults, mainly because of different injury mechanisms and timing of the injury with the growth and development of a child's face and skull base (e.g. lack of paranasal pneumatization and incomplete dentition) (Koch 2014). Further, adults and persons with osteoporosis require less force than young children with elastic bone (Bredell and Grätz 2011). The older the child is, the more similar the mechanisms and injuries are to those of adults (Koch 2014).

Soft tissue injuries

Vascular structures can be damaged, potentially resulting in considerable blood loss. Usually, a hemorrhage can be managed with packing and ligation (Kretlow et al. 2010). Also nerves can be damaged. In the facial area, the facial and trigeminal nerves are most likely to be affected. The compressing structures or injury must be localized and managed (Kretlow et al. 2010). Major trauma to the cheek may injure the parotid duct. Depth of the wound is often the determining factor in whether these injuries require repair (Kretlow et al. 2010).

Major facial trauma often involves multiple facial esthetic units: forehead, ear, eyelid, nose, cheek, and lips all have distinctive methods of management (Kretlow et al. 2010). Infections can be a major problem (Bredell and Grätz 2011).

Related injuries

Facial and skull base fractures are frequently associated with head and spinal injuries (Bredell and Grätz 2011). According to Thorén, of facial fracture patients, 25% had associated injuries; limb (14%) and brain (11%) injuries were most common, and spinal injuries occurred in 3%. Of fall-from-height (FFH) patients, about 3/4 had an associated injury, the corresponding figure for motor vehicle accident (MVA) patients being 2/3. It is important that the associated injuries do not go undetected (Thorén et al. 2010). Geriatric patients have associated injuries more often and they are more severe than those of younger adults. In addition, geriatric patients die more often of these injuries (Toivari et al. 2016). Similarly, according to Holmes et al. (2013), associated injuries can be detected in as much as half of the facial fracture patients. Of these, just 2% are cervical spine injuries (Holmes et al. 2013). While the cervical spine trauma is less frequent, it must not be neglected (Thorén et al. 2010). Further, brain injury is the most common of the life-threatening injuries in patients with facial fractures (Thorén et al. 2010).

Epidemiology and etiology of facial trauma

Trauma is a major health problem worldwide (Mock et al. 2004). About five million people die from trauma every year (Mock et al. 2004, Andersson 2014, Haagsma et al. 2016). Globally, half of the deaths are in 10- to 24-year-olds. In all those aged under 40 years, trauma is the most frequent cause of death (Salo 2010, Andersson 2014). Furthermore, several hundred million individuals are injured annually (Mock 2004, Andersson 2014). These deaths and disabilities impose an enormous burden on especially low- and middle-income countries (Mock et al. 2004). Trauma results in many consequences: physical, psychosocial, and economic; it not only affects the traumatized victim, but also the families and surrounding society (Andersson 2014). However, globally since 1990, the rates of disability-adjusted life-years have shown a significant declining trend, although region, time, age, and gender affect the patterns (Haagsma et al. 2016). The distribution of facial injuries is different within different patient populations; however, the midface or mandible is frequently affected (Holmes et al. 2013).

In 2007 in the United States, 407167 visits to the emergency department (ED) were due to facial fractures. The average age of these patients was 37.9 years and about 68% were male; 3031 patients died either in the ED or during hospitalization. The mean length of hospital stay was 6.23 days. The management of maxillofacial fractures in EDs uses considerable resources; total ED charges in the United States were estimated to be near \$1 billion in 2007 (Allerredy et al. 2011).

In 2014 in Finland, with a population of about 5.4 million, 1983 people died accidentally. Of these, 1141 (56%) were due to falls or falls from heights and 255 (13%) due to transport accidents. Of the 1983, 316 (15.9%) died while under the influence of alcohol (Official Statistics Finland 2014). In Finland, the annual incidence of facial trauma is over 3000, including only the injuries needing operation and hospital care; many more sustain minor soft tissue bruising or dental injuries. Of severe facial trauma, in Finland over half are due to violence (Lindqvist 2010).

Facial injury can arise through various etiologies. These can be categorized into groups, such as the previously mentioned traffic accidents and violence (Holmes et al. 2013), and additionally sport injuries, work-related injuries, daily life injuries (such as falls), war-related or gunshot wounds, and catastrophe injuries (Bredell and Grätz 2011). Road traffic accidents are the number one cause of facial trauma in developing countries. Even though there are more cars in more developed countries, the safer traffic environment and use of

restraints have resulted in a proportional decrease of traffic accidents as an etiologic factor for facial trauma (Andersson 2014). Up to 70% of individuals involved in traffic accidents sustain facial injuries; however, many of these are restricted to the soft tissues (Holmes et al. 2013).

High alcohol consumption is a contributing etiological factor of facial injuries, mostly due to interpersonal violence (Andersson 2014). Other contributing factors of facial injuries are, for instance, age-related such as problems with coordination, deteriorating sight, and medications. These expose the geriatric population to falls and slips (Toivari et al. 2014). Further, falls are the most frequent cause of facial fractures in the elderly. The elderly fall more often in the winter months than younger people; footwear traction devices are useful in slippery conditions (Toivari et al. 2014).

Diagnosis of facial trauma

Trauma resuscitation and treatment

The golden standard in the early treatment of severe trauma is advanced trauma life support (ATLS). It has brought structure to patient management, improving patient survival (Bredell and Grätz 2011). ATLS has introduced the ABCDE (airway, breathing, circulation, disability, exposure) system, where the management always starts from the most urgent condition (Fildes 2008). Trauma mortality depends on many factors, such as ATLS training, but also on well-developed trauma systems. e.g. advanced pre-hospital care (Abu-Zidan 2016). Monitoring is useful: electrocardiographic monitoring, pulse oximetry, ventilator rate, arterial gas blood levels, blood pressure, urinary and gastric catheters, and radiographs (Fildes 2008). The Glasgow Coma Scale (GCS) is used as a clinical measure of brain injury (Fildes 2008). GCS can be difficult to interpret in a facial trauma patient because these injuries can affect both visual and verbal response (Bredell and Grätz 2011). Chest and pelvic radiographs, and spine radiographs if needed, can be taken with a portable x-ray unit in the resuscitation area (Fildes 2008). Focused assessment with sonography for trauma (FAST) can be used to detect intra-abdominal blood (Fildes 2008). US can also quickly exclude a clinically relevant pneumothorax (Soult et al. 2015). CT is taken after early examination and management (Fildes 2008). Intravenous contrast is needed to detect active bleeding and to enhance visibility (Singh and Neutze 2012).

Understanding the anatomy and radiological features of the maxillofacial area is vital in the interpretation of facial trauma (Holmes 2013). Facial trauma without airway obstruction or major bleeding should be treated after the patient is in stable condition and life-threatening injuries have been managed. Some maxillofacial fractures are not easy to detect early in the process so re-evaluation is needed (Fildes 2008).

Clinical diagnosis of facial trauma

After the life-saving procedures, a brief history from a conscious patient can be taken (Andersson 2014). This can yield important facts about e.g. the injury mechanism. A medical history is also valuable (Andersson 2014).

The examination consists of inspection and palpation (Andersson 2014), and it should be divided into extraoral and intraoral phases (Bredell and Grätz 2011). Extraoral examination consists of inspecting various aspects: swelling and asymmetry of the face, hematomas, ecchymosis, eye movement and position, normal movement of different facial movements, other abnormal features, blood from ears or nose, and problems with nasal breathing. After inspection, one should palpate the bony structures (Bredell and Grätz 2011). Further, the function of sensory and motor nerves of the face should also be tested (Lindqvist 2010). Examination of the facial area should be conducted from the outside to the inside; management of these should occur in the opposite order, if possible (Andersson 2014). Intraoral examination includes inspecting for swelling or lacerations in the oral cavity, symmetry of mouth opening, occlusion, and condition of teeth. Moreover, one should palpate the alveolar ridges and vestibula and note any crepitations and movement; testing the stability of the jaws is also important (Bredell and Grätz 2011).

Even with multiple facial fractures, the skin of the face may remain intact. Conversely, in the majority of minor facial trauma, only soft tissue injuries are detected (Lindqvist 2010). Most of the tissue defects can be examined and treated under local anesthesia; however, local anesthesia can affect neurological status, so this should be examined first (Lindqvist 2010).

When examining the face, it is important to remember to also look for signs of skull base fractures, e.g. hemotympanum or cerebrospinal fluid leak from the nose or the ear (Bredell and Grätz 2011). Associated injuries should be kept in mind, especially in high-energy trauma (Bredell and Grätz 2011).

Diagnostic imaging of facial trauma

Precise radiological diagnosis is key in the treatment of facial injury. A systematic approach is needed when assessing the images. Special attention should be given to air-bone interfaces, continuity of the cortex, and symmetry (Holmes et al. 2013). Further, it is important to use standardized nomenclature and a common language to improve communication between radiology and the surgical services. This enables accurate diagnosis, possibly expediting the treatment of patients needing surgery (Ludi et al. 2016).

Radiography

Plain radiographs have a major role in the early treatment of a trauma patient (Holmes et al. 2013). Also, MDCT, the reference standard, is not always available.

Before positioning a patient for the plain radiograph for suspected facial trauma, injury of the head and cervical spine should be excluded so that further damage is not caused (Holmes et al. 2013). Even though improved access to CT has made it the golden standard, most mandibular fractures can be assessed on panoramic radiographs (MacLeod 2012). Plain radiographs are usually requested in two perpendicular planes. For suspected mandibular fracture, panoramic radiograph and PA/AP x-ray of the mandible can be taken. Town's view, half-axial projection, (<http://www.hus.fi/ammattilaiselle/hus-kuvantaminen/Natiivi%20%20pn%20oppaat/Kallon%20natiivir%C3%B6ntgen,%20hyv%C3%A4n%20kuvan%20kriteerit.pdf>) is an option for identification of condylar fractures (Bredell and Grätz 2011). For the midface, occipitomeatal views (a.k.a. Waters' views) with an angle of 15° and 30° can be obtained. For nasal fractures, lateral views can be useful. For suspected frontal fractures, a lateral skull view is appropriate (Bredell and Grätz 2011). However, nowadays, for suspected craniofacial trauma patients, plain radiographs are performed often in centers where CT is not available or before CT on patients suffering from less serious trauma (Bredell and Grätz 2011).

Most fractures of the extremities are still initially imaged with plain radiographs due to their smaller cost and availability. Further, they are easier to interpret than MDCT (Geijer 2006). Conversely, plain radiographs can sometimes be difficult to interpret because the findings are not always distinct (Holmes et al. 2013). Radiography frequently underestimates the injuries (Geijer and El-Khoury 2006). Thus, further imaging, including thin section MDCT with multiplanar reformation (MPR) and three-dimensional (3D) images (Geijer and El-Khoury 2006, Holmes et al. 2013) and CBCT (Holmes et al. 2013), may be needed.

Computed tomography and multidetector computed tomography

Computed tomography (CT) creates images of slices of the patient. These slices can be of different thickness, even under 1 mm using small x-ray detectors and a fan-shaped beam. MDCT, in which multiple CT slices are acquired simultaneously, reduces scanning time and motion artifacts and further enhances spatial resolution. With post-processing, reformatted or 3D volume and surface-rendered images can be made. Images of the slices can be seen in axial, coronal, and sagittal multiplanar reformatted images (MPR). If needed, images can also be viewed in any other plane (Rydberg et al. 2000, Bastos et al. 2009, Pogrel 2014). The CT has high-contrast resolution – under 1% difference in the density of tissues can be detected. The density is represented by a CT number or the Hounsfield unit, each pixel has its own CT number (Pogrel 2014). Compared with conventional radiographs, an advantage of the CT is that overlapping of images of structures outside the area of interest is eliminated (Pogrel 2014). CT can, to some extent, also be used as an alternative to US or MRI when these are contraindicated, e.g. in open wounds or in the presence of metal or pacemakers (Geijer and El-Khoury 2006).

CT results in better classification of the fractures, but more importantly it improves the detection of the fractures, enabling better surgical planning and results; 3D images can help the surgeon to understand spatial relation, while MPR images give the exact bony details (Geijer and El-Khoury 2006).

Further, CT can be very helpful in monitoring the healing of a fracture, to detect nonunion or problems with the hardware (Geijer and El-Khoury 2006). When avoiding excessive hardware artifacts, varying scan planes can be of assistance. With MDCT and better reconstruction algorithms, hardware creates less problems than previously, although soft tissue near hardware can be difficult to interpret (Geijer and El-Khoury 2006). The quality of the images is not jeopardized by plaster casts or positioning of patients; the patient just lies down (Geijer and El-Khoury 2006). In addition, little patient cooperation is needed since the image acquisition time is short (Lee 2004).

Filtered back projection (FBP) is the standard image reconstruction method, in which an increase in spatial resolution directly correlates with increased image noise (Korn 2012). Recently, iterative reconstruction methods (IR) have been developed that reduce the level of image noise in order to either lower radiation dose while maintaining image quality or only improve the quality of images. One of these is the adaptive statistical iterative reconstruction (ASiR, GE Healthcare, Milwaukee, WI, USA). Another more complex algorithm is the model-based iterative reconstruction (MBIR) algorithm VEO (GE Healthcare,

Milwaukee, WI, USA) (Hultenmo et al. 2016). Dual-energy CT is a new imaging technique (Aran et al. 2014) that can be used to improve material differentiation (Fornaro et al. 2011). X-rays with different energies, predominantly polychromatic spectra, are required to perform dual-energy CT; the detector also needs to be able to differentiate large amounts of different energies. There are several technical approaches to meet these requirements, one of which is the dual-source CT. For diagnostic purposes, it offers the possibility to exploit spectral information (Johnson and Kalender 2011).

In conclusion, in emergency assessment CT is increasingly used. MDCT in ever-increasing versions is an excellent tool in emergency situations for polytrauma patients, but also for patients with complex trauma to the extremities. With CT, at least two perpendicular planes, usually axial and coronal, are needed. Sagittal view can also be useful. 3D can be used as an aid for getting a larger picture, but careful examination of each plane is the basis of assessment (Bredell and Grätz 2011).

Cone-beam computed tomography

In contrast to traditional fan-beam CT, which scans slices in one field, CBCT is a volumetric tomography from which different planes of volume slices can be made (Pogrel 2014). The patient's head is stabilized while a single 360° scan is made (Luminati and Tagliafico 2014). CBCT has many advantages compared with MDCT. CBCT is a smaller unit and the radiation dosage is lower due to the cone-shaped x-ray (Luminati and Tagliafico 2016). 3D reconstructions can be made from the reformatted two-dimensional (2D) data (Luminati 2016). The resolution is high (Pogrel 2014). However, as with conventional CT, metal objects cause artifacts in CBCT (Pogrel 2014).

CBCT has found its place, especially in dental and maxillofacial imaging (Luminati and Tagliafico 2014). CBCT images frequently involve areas outside the region of interest (ROI), even though this should be limited through field of view (FOV) reduction (Pauwels 2015). According to the European Commission guidelines, the entire dataset must be evaluated, not just the ROI (Pauwels 2015, EC 2012). Thus, depending on the area, an oral or medical radiologist can be warranted (Pauwels 2015). The CBCT is also increasingly used in the emergency assessment (Bredall 2010). When conventional CT is not available, CBCT can be reliably used e.g. in patients with suspected orbital floor fracture (Johari et al. 2016). However, often the CBCT imaging is performed with the patient in an upright position, and thus, is not suitable for multitrauma patients (Brisco et al. 2014).

Magnetic resonance imaging

MRI differs from the previous modalities because it does not use ionizing radiation (Pogrel 2014). MRI is based on magnetic fields aligning protons in the body, electronically recording when they return to baseline; this information is used to make an image (Pogrel 2014).

MRI is the best imaging modality for the assessment of acute ischemia (Chalela et al. 2007) and spinal cord and adjacent soft structures (Gold 2015). It has excellent soft tissue contrast and can also be used in the evaluation of acute musculoskeletal problems of outpatients, when other modalities have not provided a diagnosis (Broder 2011). MRI is less commonly an emergency tool (Rankey et al. 2008). Its availability is limited and residents are less experienced with MRI interpretation (Rankey et al. 2008). Further, use of MRI is expensive and MR imaging requires more time (Broder 2011). There are a few contradictions; patients with claustrophobia or metallic foreign objects, metal clips, or pacemakers cannot be examined (Pogrel 2014), except if these are known not to interfere with MRI.

Ultrasound

As previously discussed, US is an important part of the initial screening of a trauma patient (FAST). In the assessment of facial trauma, US seems not to have potential for wider use. However, US with a linear array transducer, is highly accurate in the detection of suspected orbital floor fractures in patients without complex or severe facial or head injuries, but its lower sensitivity limits the usability compared with CBCT (Johari et al. 2016). In the material of Menon et al. (2016), with ZMC fractures US showed 100% sensitivity at three of four articulations. However, the amount of displacement could not be evaluated, making the planning of management more difficult (Menon et al. 2016). US can be used to detect nasal, orbital, zygomatic arch, and anterior maxillary wall fractures, and it might be useful in detecting extracapsular subcondylar fractures. However, it has limitations in posterior orbital floor and intracapsular condylar fractures, complex facial fractures, and, as previously discussed, undisplaced fractures (Adeyemo and Akadiri 2011). Despite these drawbacks, US can be very useful because of its real-time images, obviating radiographic imaging, especially for polytrauma patients in emergency situations (Menon et al. 2016).

Radiation dose

There are three principles that, when fulfilled, allow the use of medical radiation. Firstly, the benefits must outweigh the harms. Secondly, the radiation dose must be kept as low as reasonably achievable. Thirdly, the individual radiation dose may not exceed the regulated maximum levels (Nieminen 2016 a). The adverse effects of radiation can be divided into deterministic (instantaneous) and stochastic (long-term) effects. In medical radiology, deterministic effects are rare. However, stochastic injuries may result even from low doses. Often, to perceive the overall picture, the effective dose of a certain examination is compared with the equivalent time an individual is exposed to natural radioactivity. Panoramic radiograph is equivalent to 2 days, facial CBCT scan 7 days, facial CT scan 1.5 months, and abdominal CT scan 2 years of natural radioactivity (Nieminen and Oikarinen 2016 b). Accordingly, CT involves marked absorbed radiation doses to patients. Especially with children, it is important to keep the radiation dose as small as possible. If the clinical problem permits, low-dose CT technique can be used, even though this reduces the image quality (Pogrel 2014). During the head or paranasal sinus CT scan also the surrounding structures, e.g. radiosensitive eyes and the thyroid gland, absorb radiation (Bassim et al. 2005, Brem et al. 2007). With high-resolution CT, the doses are well below levels that cause clinical damage (Bassim et al. 2005). However, it is important to limit the radiation dose to the eyes (lenses), especially in patients requiring multiple scans and in the younger population (Brem et al. 2007). Bismuth-containing latex eye shields are used to reduce the surface dose. In paranasal CT, this can be reduced by 40%. Artifacts caused by these shields are almost unnoticeable in the bone window. However, interference with quantitative information can occur (Hein et al. 2002).

AIMS OF THE STUDY

The multidetector computed tomography (MDCT) findings of patients with suspected facial trauma were assessed. Further, the optimal postoperative imaging method of facial trauma was determined.

Specific objectives of the studies were as follows:

I Falls from heights

To assess the MDCT findings, including occurrence, pattern, and severity of facial injuries, following a fall-from-height accident.

II Falling accidents

To assess the MDCT findings of facial trauma resulting from falling accidents in different age groups.

III Violence

To determine the MDCT findings of facial trauma in victims of interpersonal violence.

IV Motor vehicle accidents

To assess the MDCT findings of facial fractures in motor vehicle accident victims, elaborating the incidence and spectrum of these injuries.

V Computed tomography of facial fracture fixation

To assess the optimal postoperative computed tomography imaging method for visualization of facial bony structures near osteosynthetic material.

MATERIALS AND METHODS

This study was conducted at the Töölö Trauma Center, Helsinki University Hospital, Finland, which serves a population of over 1.3 million people. The main clinical departments are those of orthopedics and traumatology, neurosurgery, and plastic surgery. The Töölö Trauma Center is the leading level 1 trauma center in Finland.

I-IV Falls from heights, Falling accidents, Violence, Motor vehicle accidents

The study period began in August 2000 (when the MDCT scanner, Lightspeed QX/I, GE Medical Systems, Milwaukee, WI, USA, was installed) and ended in September 2005, altogether 62 months. Using a picture-archiving and communications system (PACS), we retrieved and reviewed all 2413 MDCT requests for suspected facial injury (Table 1). We excluded patients without acute trauma or traumatic etiology. A few patients were injured more than once on different occasions, and these incidents were treated as separate cases. Further, children under 15 years were not included because their primary care institution is the Children's Hospital. The study protocol was approved by the hospital's ethics committee.

All patients underwent a non-contrast four-section multislice CT scan with 4 x 1.25-mm collimation, pitch 3, tube current 40 mA, voltage 140 kV, table feed 3.75 mm/s, rotation time 1.0 s, and approximate total exposure time of 45 s. In addition to the 1.25-mm axial images reconstructed with 0.8-mm increment, routine 1.3-mm coronal-plane multiplanar reformation (MPR) images were reconstructed with 1.3-mm increment. When clinically needed, sagittal plane MPRs and 3D volume-rendering images were obtained; post-processing was done on an Advantage Workstation (3.0–4.3) (GE Medical Systems, Milwaukee, WI, USA). The MDCT scans were reviewed using clinical workstations (Agfa Impax DS3000 Impax v. 4.5; Agfa-Gevaert, Mortsel, Belgium). Each scan was interpreted by two researchers (Elina Peltola and Mika Koivikko) independently and any disagreements resolved by a second consensus reading.

The injuries were classified as nasal bone fractures, NOE fractures, orbital fractures, zygomatic arch fractures, ZMC fractures, LF I, LF II, and LF III

fractures, maxillary fractures, mandibular fractures, frontal bone fractures, skull base fractures, and other fractures. In the classification, nasal bone fractures, orbital fractures, zygomatic arch fractures, maxillary fractures, and frontal bone fractures included isolated fractures not part of a pattern (NOE, ZMC, LF I, LF II, LF III). Frontal bone injuries were subsequently categorized according to Manolidis (2004) into five groups: type 1 (anterior wall fracture, minimal comminution), type 2 (anterior wall fracture with comminution), type 3 (both anterior and posterior wall fracture, posterior wall fractures without remarkable displacement or dural injury), type 4 (both anterior and posterior wall fracture, dural injury and cerebrospinal fluid leak), and type 5 (like type 4 with additional soft tissue or bone loss or severe disruption of the anterior cranial fossa). Mandibular fractures were categorized into coronoid, condylar, subcondylar, ramus, angle, body, parasymphiseal, symphyseal, and isolated alveolar process fractures. Orbital fractures were classified as lateral, medial, roof, or floor fractures, also including information about whether or not they were blow-out fractures. Fractures were classified as unilateral or bilateral. LF I, II, and III fractures were categorized as symmetric (same type of fracture on both the right and left side of the face, i.e. bilateral) or asymmetric (unilateral fracture or a different kind of LF fracture on the right or left side). Further, all combinations of fractures were assessed. Additionally, effusions of the paranasal sinuses (maxillary, ethmoid, frontal, and sphenoid) were assessed; however, chronic appearing paranasal sinus mucosa thickening was not considered to represent free intrasinus fluid (Lambert et al.1997).

Table 1. Of the 2413 MDCT requests within the 62-month study period (August 2000-September 2005), the number of patients with each of the four etiologies investigated is presented, with the number of patients with fractures provided in parentheses.

I Falls from heights	II Falling accidents	III Violence	IV Motor vehicle accidents
155 (118)	500 (329)	727 (538)	374 (262)

I Falls from heights: Of the 2413 requests, 155 patients met the criteria of falling from a height (mean age 42.6 years, range 15.3–76.7 years). Of these patients, 134 (86%) were male and 21 (14%) female. The estimated falling height was usually mentioned in the emergency-room MDCT request, and it was recorded for each patient. Associated injuries (brain, thorax, abdomen, pelvis, spine, extremities) were also assessed according to the imaging reports. Mann-Whitney rank-sum test, Fisher’s exact test, and Chi-square test were used.

II Falling accidents: This category comprised 500 patients (mean age 57 years, range 17–96 years), 259 (52%) were female and 241 (48%) male. Of all of these patients, 391 (78%) slipped or tripped from standing height, and 109 (22%) fell on stairs. Patients who fell from a height were excluded due to a different injury mechanism. The timing of the facial CT with the initial trauma workup was also recorded. Special attention was given to the dislocation of fractures in conjunction with clear sinus.

III Violence: This group comprised 727 patients (mean age 37 years, range 15–86 years) with suspected facial injury due to interpersonal violence. Of these patients, 583 (80%) were male and 144 (20%) female. Excluded due to a different mechanism were victims of gunshot wounds and patients in whom the violence resulted in a fall from height. Trauma to the nasolacrimal canal was reported with NOE fractures.

IV Motor vehicle accidents: Altogether 374 patients (mean age 34 years, range 15–80 years) had a suspected facial trauma due to a MVA; 271 (72%) were male and 103 (28%) female. Patients included were involved in a passenger car, van, truck, motorcycle, moped, or bus accident. Excluded were cyclists and pedestrians as well as patients involved in snowmobile or sports-related MVAs due to the different mechanisms of injury. Motor vehicles were divided into two groups: motorized two-wheelers and those involving a passenger car or a larger vehicle. Further, the MVAs were divided into collisions and run-off-road accidents. The former group included collisions with other motor vehicles or objects such as trees. The latter group included vehicles going off the road or rolling over. If reported, the use of restraining systems was also registered. The frequency distribution of the categorical variables was compared between the groups with Pearson's Chi-square test.

V Computed tomography of facial fracture fixation

This study was conducted by scanning a phantom with a 64-slice CT, CBCT, and a high-definition multislice CT with dual-energy scan (providing monochromatic images of 70, 100, 120, and 140 keV energy levels) and iterative reconstruction (IR) methods. In ASiR, both 10% and 30% levels of blending were used with a 64-slice scanner. Additionally, the ASiR reconstruction with 50% blending at the high-definition (HD) mode, 40% blending at the dual-energy Gemstone spectral imaging (GSI) mode, and the model-based iterative technique VEO was applied as an alternative reconstruction method with the high-definition multislice CT. The ASiR blending levels were chosen to resemble typical clinical settings. The devices and protocols are presented in Table 2.

Table 2. Devices and protocols. Planmed Verity (Planmed Oy, Helsinki, Finland). GE Discovery CT750 HD and GE Lightspeed VCT (GE Healthcare, Milwaukee, WI, USA).

Reprinted and adapted with permission from Peltola EM, Mäkelä T, Haapamäki V, Suomalainen A, Leikola J, Koskinen SK, Kortessniemi M, Koivikko MP. CT of facial fracture fixation: an experimental study of artefact reducing methods. Dentomaxillofacial Radiology 2017; 46: 20160261. doi 10.1259/dmfr.20160261

Protocol	Protocol values
A. Planmed Verity (CBCT)	96 kV, 10 mA normal dose 96 kV, 9 mA low dose
A1. High resolution	
A2. High resolution + metal suppression	
A3. Standard	
A4. Standard + metal suppression	
A5. Low dose	
A6. Low dose + metal suppression	
B. GE Discovery CT750 HD	
B1. "Facial bone"	Axial series: Helical full 0.4 s Detector coverage: 40 Slice thickness: 0.625 mm, Interval 0.312 Pitch / Speed 0.516:1 / 20.62 Manual mA 120 kV – 40 mA SFOV: Head, DFOV: >23 Calculation algorithm: DETL, ReconOption: PLUS, W/L 2600/600, ASiR 30% Recon2: 0.625 mm/0.312 mm; SOFT, ReconOption: FULL, W/L 400/40 ASiR 30% Recon3: 1.25 mm/1.25 mm, Detail, ReconOption: FULL, W/L 2600/600 ASiR 30% Image matrix size 512 x 512
B2. "Facial bone" HD	Axial series: Helical full 0.4 s, HiRes mode ON Detector coverage: 20 Slice thickness: 0.625 mm, Interval 0.312 Pitch / Speed 0.531:1 / 10.62 Manual mA 120 kV – 40 mA SFOV: Head, DFOV: >23 Calculation algorithm: HD DETL, ReconOption: PLUS, W/L 2600/600, Volume ASiR 50% Recon2: 1.25 mm/1.25 mm, HD Detail, ReconOption: FULL, W/L 2600/600 ASiR 50% Image matrix size 512 x 512

B3. "Facial bone" VEO	Axial series: Helical full 0.4 s Detector coverage: 20 Slice thickness: 0.625 mm, Interval 0.312 Pitch / Speed 0.531:1 / 10.62 Manual mA 120 kV – 40 mA SFOV: Head, DFOV: 25 Calculation algorithm: detail, ReconOption: PLUS-E, W/L 2600/600, ASiR 30% Recon2: 0.625 mm/0.625 mm, STND, VEO IR Image matrix size 512 x 512
B4. GSI mono-chromatic 70 keV	Slice thickness 0.625 mm 0984:1 39, 37
B5. GSI mono-chromatic 100 keV	Rotation time 0.5 s. Detector coverage 40 mm, estimated dose 10.18 mGy. Image matrix size 512 x 512
B6. GSI mono-chromatic 120 keV	GSI-51 preset GSI ASiR 40% Phase 75–75%
B7. GSI mono-chromatic 140 keV	MARS used; GSI filter not in use.
C. GE Lightspeed VCT	Slice thickness 0.625, pitch and speed (mm/rotation) 0.516: 1 20.62 Rotation time 0.4 s, 120 kV, 40 mA Image matrix size 512 x 512
C1. "Facial bone" ASiR 30%	
C2. "Facial bone" ASiR 10%	
C3. "Facial bone" ASiR 30% + bone	
C4. "Facial bone" ASiR 10% + bone	
ASiR, adaptive statistical iterative reconstruction; DFOV, display field of view; GSI, gemstone spectral imaging; IR, iterative reconstruction; mA, milliampere; SFOV, scan field of view; VCT, volume CT; VEO, model-based iterative reconstruction technique	

The multislice CT scanners used were GE Lightspeed VCT 64-slice model and GE Discovery CT750 HD high-definition scanner (GE Healthcare, Milwaukee, WI, USA). The dual-energy scans and use of model-based iterative technique (VEO) is included only in the GE Discovery CT750 HD multislice CT scanner. The CBCT scanner used was Planmed Verity (Planmed Oy, Helsinki, Finland) with an x-ray tube with a tungsten target, anode voltage set to 96 kV, and anode current 9-10 mA (depending on the protocol). The scanner has a 20 × 25-cm flat-panel amorphous silicon detector enabling a FOV of 13 × 16 cm with a scan time of 18 s.

The phantom was a not previously frozen head of a deceased pig, chosen because, even though somewhat larger, the bone structure reasonably resembles the human face. An oral and maxillofacial surgeon (Junnu Leikola) performed

two sagittal osteotomies on the mandible to resemble two fracture lines. Next, two commonly used plates – a 2.0 titanium miniplate (W Lorenz, Jacksonville, FL, USA) and a 2.3 titanium miniplate (KLS Martin, Tuttlingen, Germany) – were attached to the mandible using two different-sized screws (1.5 to 2.0 mm). One of the screw holes was drilled too large to resemble osteolysis. Another screw was intentionally left poorly attached. Similar to an authentic human mandibular surgery, the soft tissues were subsequently closed. All scans were completed within two hours after preparation of the phantom. A radiologist with 11 years of subspecialty experience in musculoskeletal and trauma imaging (Mika Koivikko) reconstructed the reformats in three standard orthogonal planes using a three-dimensional (3D) workstation (GE Advantage Workstation 4.6). A standard clinical 1 mm slice thickness was used. Attention was given to ensure that positioning and slice orientation were identical across all scans.

Two radiologists – Ville Haapamäki (interpreter *a*) and Anni Suomalainen (interpreter *b*) – with 10 and 16 years of subspecialty experience in musculoskeletal and trauma radiology and oral radiology, respectively, assessed the image quality (Agfa Impax 6.5) separately and without knowledge of which device or protocol yielded which image. For each scan, interpreters assessed ten different items familiar to the interpreters before completing the assessment. These items were blooming artifacts, streak artifacts, osteolysis (fifth screw on the right side), loose screw (third screw on the left side), fracture line further (≥ 5 mm) from the screw and the plate, fracture line in the direct vicinity (< 5 mm) of the screw and the plate, bony structure further (≥ 5 mm) from the screw and the plate, bony structure in the direct vicinity (< 5 mm) of the screw and the plate, soft tissue further (≥ 5 mm) from the screw and the plate, and soft tissue in the direct vicinity (< 5 mm) of the screw and the plate. The interpreters discussed the items to ensure uniformity in the evaluation criteria. The Likert scale was used as a tool in the assessment. Elina Peltola analyzed the assessments.

A semi-quantitative analysis of the streak artifacts was conducted by a physicist (Teemu Mäkelä) using an in-house MATLAB (Mathworks, Natick, MA, USA) program and 3D Slicer software (NA-MIC). Contrast investigations of a relatively homogeneous soft tissue region near the metal implant were performed after matching the datasets with rigid co-registrations. Because of differences in the imaging techniques, the image intensity values (0 for fatty tissue and 1 for muscle tissue) were normalized. All datasets were similarly analyzed and 5- and 95-quantile values were recorded at different distances from the metal. This procedure aimed to provide both hypo- and hyper-intense signal artifacts relative to the discernibility between the two fixed tissue types. The resulting graphs were qualitatively examined for the extent and magnitude of the artifact.

RESULTS

I Falls from heights

Inclusion criteria were met by 155 patients (134 male and 21 female), 118 (104 males and 14 females, age 15.3–76.7 years, mean 42.6) of whom had 247 facial or skull base fractures (Figures 3-5). The number of patients with fractures can be seen in Table 3. Multiple non-contiguous fractures were detected in 68 patients (44% of all patients and 58% of those with fractures, Table 4).

The falling height was reported in 85% of all cases. The mean height was 5.7 m (range 0.4–25), in those with a fracture 6.0 m (range 0.4–25) and in those without a fracture 5.0 m (range 0.4–13). Differences in falling heights were not significant between genders. Patients who sustained LF II, LF III, or frontal bone fractures had fallen 7.2 m (range 1.5–25, median 5.8, SD 5.0.), compared with 5.3 m (range 0.4–17, median 3.5, SD 4.3) in those with other facial fractures ($p=0.021$, Mann-Whitney rank-sum test). The average falling height was slightly lower in patients with no fracture than in those with a fracture ($p=0.35$, Mann-Whitney rank-sum test).

Thirty isolated frontal bone fractures were detected (Table 5). Altogether 14 patients had 18 isolated fractures of the orbit (Table 6). Of the maxillary bone fractures, four were bilateral and eight unilateral. Of the 57 ZMC fractures, 53 were unilateral and were assessed predominantly (53 of 57 cases) in males. Nasal bone fractures were present in 31 cases; 27 of these were associated with other facial fractures. In 24 patients, there were altogether 48 mandibular fractures (Table 7). Fractures of the mandible were more common in the group of 29 patients aged 15-25 years. Of these, 11 had a fractured mandible, whereas of the group of 126 patients aged over 25 years only 13 had a mandibular fracture ($p=0.00021$).

LF fractures occurred almost exclusively in males (20 of 21 cases). Further, only one of the 37 patients suffering from a skull base fracture was a female.

Skull base fractures correlated with other maxillofacial fractures. Of the 114 patients (of all 118 fractured patients, 4 patients with only an isolated skull base were not included in these 114), 33 had a simultaneous skull base fracture. Conversely, in the 41 without other maxillofacial fractures, only four had a skull base fracture ($p=0.018$, Fisher's exact test). Of these 33 cases with a

facial fracture and an associated skull base fracture, 24 sustained LF II, LF III, or frontal bone fractures, whereas of the 81 patients with facial fractures with no skull base fracture, only 14 had LF II, LF III, or frontal bone fractures ($p=0.000000029$, Chi-square test). Further, skull base fractures occurred often in association with LF II (9 of 14), LF III (8 of 13), and frontal bone fractures (21 of 30). Fractures of the skull base were also quite common in ZMC (19 of 57) and nasal fractures (11 of 31), which often occurred in conjunction with LF II, LF III, and frontal bone fractures.

Of the 118 patients with a fracture, 80% had effusions of the sinuses (Table 8). Of the 23 patients with a fracture and clear sinus sign (CSS), two had zygomatic arch fractures, three ZMC fractures, three skull base fractures, three other maxillary fractures, five nasal fractures, and 11 mandibular fractures.

An associated injury was seen in 98 (83%) of the 118 cases with a facial or skull base fracture: 47 cases of contusion or intracerebral hemorrhage, 26 cases of subarachnoid or intraventricular hemorrhage, 24 subdural hemorrhages, 6 epidural hemorrhages, 23 cases of intracranial air, 50 thorax injuries, 20 abdomen injuries, 16 traumas to the pelvis, 27 traumas to the spine, 45 traumas to the upper extremity, and 24 traumas to the lower extremity.



Fig. 3. A 52-year-old male falling 10 m from a scaffolding and sustaining numerous fractures, including a ZMC fracture (arrows). Sinus effusion (arrowhead).

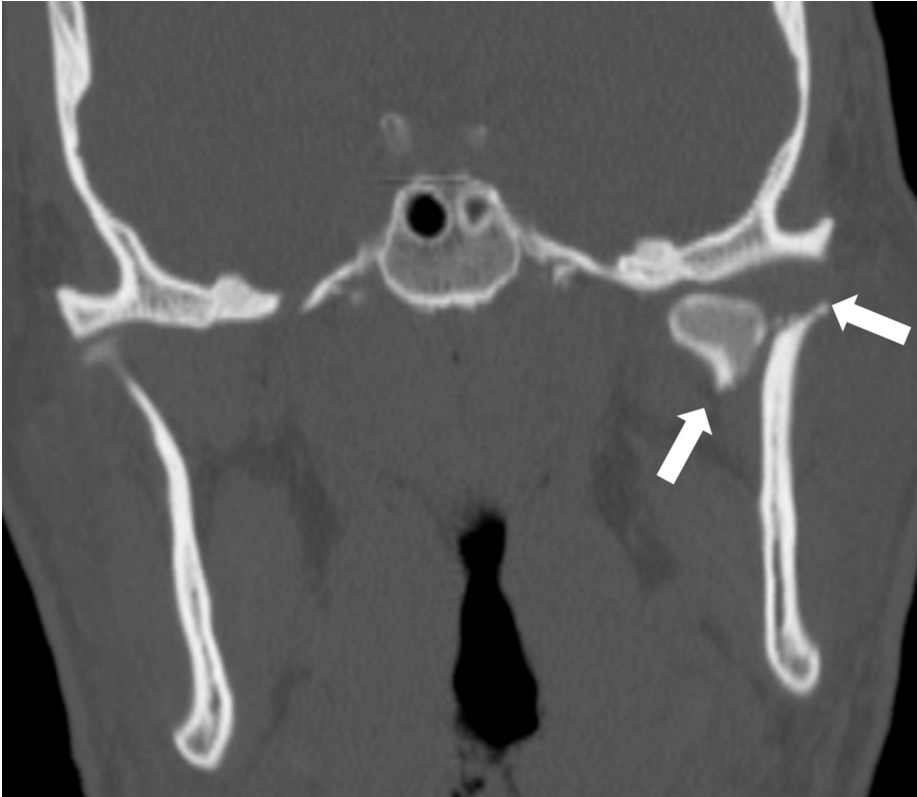


Fig. 4. A 20-year-old male falling 4 m onto asphalt and sustaining a subcondylar fracture (arrows).

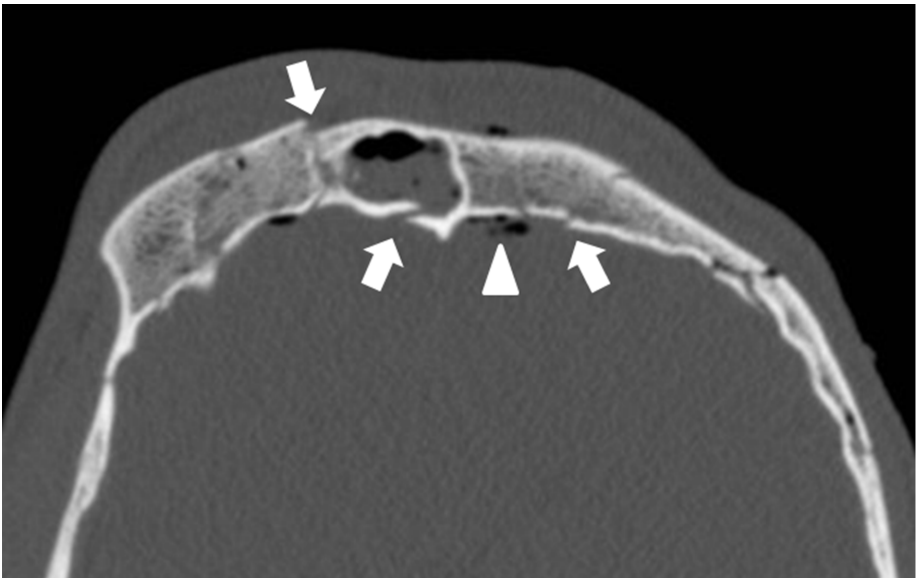


Fig. 5. A 19-year-old male jumping 10 m headfirst to asphalt and sustaining, among other injuries, a type 5 frontal fracture.

II Falling accidents

Five hundred patients aged 17–96 years (mean age 57 years) were included; 48% (n=241) were male (aged 17–91 years, mean 53 years) and 52% (n=259) female (aged 18–96 years, mean 61 years). Of all patients, 66% (n=329) had 515 facial or skull base fractures altogether: of all male patients, 77% (n=186) had 327 fractures, of all females, 55% (n=143) had 188 fractures (Figures 6-9). Multiple non-continuous fractures were found in 123 patients (25% of all patients and 37% of those with a fracture, Table 4). The age distribution of patients with facial fractures had two peaks; this was especially notable in fractured females, with the highest peaks being in 50- to 55-year-olds and in 80- to 85-year-olds. Eighty-one percent of patients with a fracture (268 of 329) underwent facial CT in conjunction with the initial trauma workup at the Töölö Trauma Center. With the remaining 19%, CT was taken after a mean of 29 hours (range 1–502 hours, median 5 hours). Overall, imaging of patients with a fracture was done 5 hours after the initial screening.

The falling mechanism was analyzed and divided into two groups: those who slipped or tripped from a standing height and those who fell on stairs. Seventy-eight percent (n=391) slipped or tripped (aged 17–96 years, mean 58 years; 174 male, 17–91 years, mean 53 years and 217 female, 18–96 years, mean 62 years), and 22% (n=109) fell on stairs (aged 18–91 years, mean 54 years; 67 male, 18–83 years, mean 53 years, 42 female, 18–91 years, mean 55 years). Of the patients who slipped or tripped, 62% sustained a total of 346 (mean 1.4) fractures, and of those who fell on stairs, 79% had 169 (mean 2.0) fractures.

The number of fractures and fracture subtypes are categorized in Tables 3 and 5-7. All nine NOE fractures were unilateral, as were 125 of 126 ZMC fractures and 41 of 46 maxillary fractures. LF I, II, or III fractures were detected in 43 patients (33 males); 11 had asymmetric, 24 symmetric, and eight both asymmetric and symmetric fractures. Skull base fractures were frequently associated with a facial fracture; only four of 43 patients with a skull base fracture had no facial fracture, further, 24 had multiple facial fractures. NOE fractures were quite often associated with skull base fractures (3 of 9, 33%). This correlation between facial and skull base fractures was particularly remarkable with high-energy facial fractures such as frontal fractures (8 of 14, 57%) and LF III fractures (11 of 17, 65%).

Of non-fractured patients, 84% (n=143) had clear sinus sign, compared with 25% (n=83) of fractured patients (Table 8). In four of these 83 cases, imaging was done over a week after the injury, and thus, these were not included in further

analysis of CSS) in fractures. Further, fractures not adjacent to sinuses (orbital superior and lateral wall, nasal, maxillary alveolar, mandibular) and those skull base fractures not affecting the sinus walls were not included. Twenty patients had CSS and a fractured sinus wall: 10 fractures of the orbit, 5 ZMC, 4 other maxillary, 1 skull base, and 1 LF III fracture; of these, a nondisplaced fracture was detected in 3, 2, 3, 1, and 1, respectively.

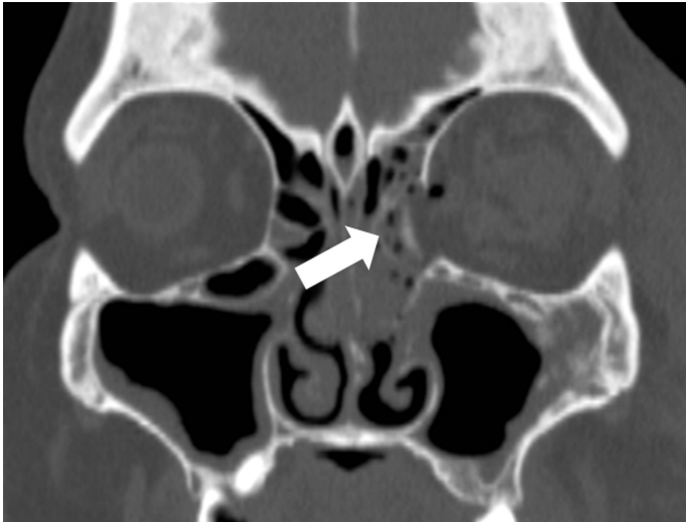


Fig. 6. After a fall, a 58-year-old female sustained a left medial wall blow-out fracture.

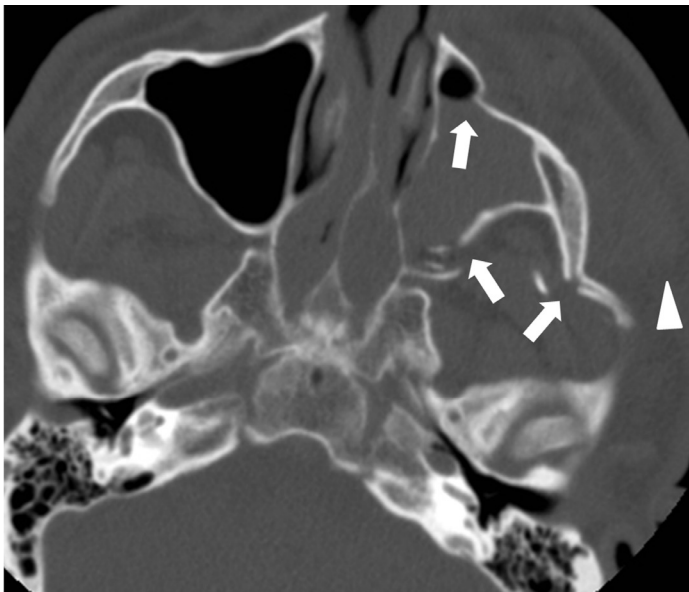


Fig. 7. Zygomatic complex fracture (ZMC, arrows) and soft tissue edema in a 37-year-old male patient who had fallen down stairs under the influence of alcohol.

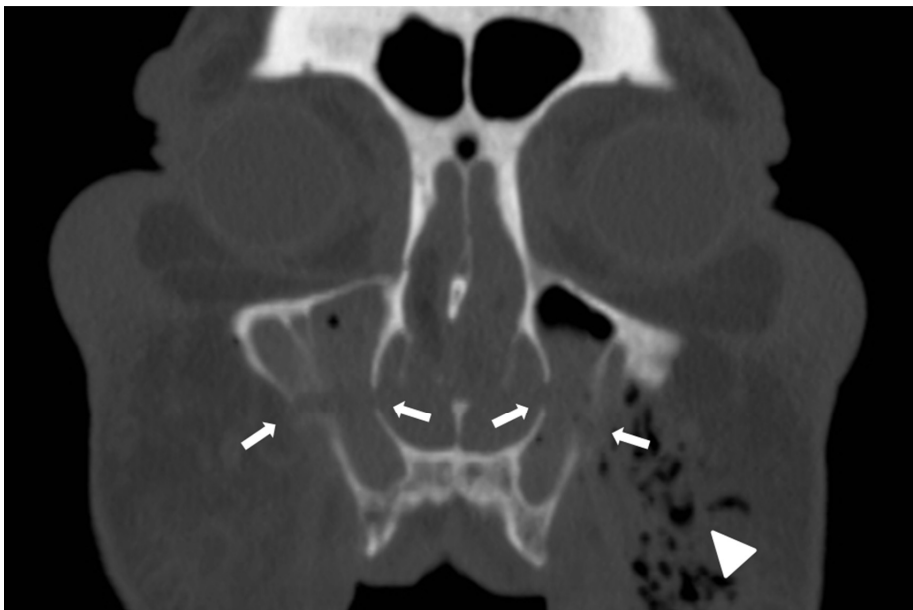


Fig. 8. Le Fort I fracture (arrows) and subcutaneous air (arrowhead) in an 85-year-old female after a fall.

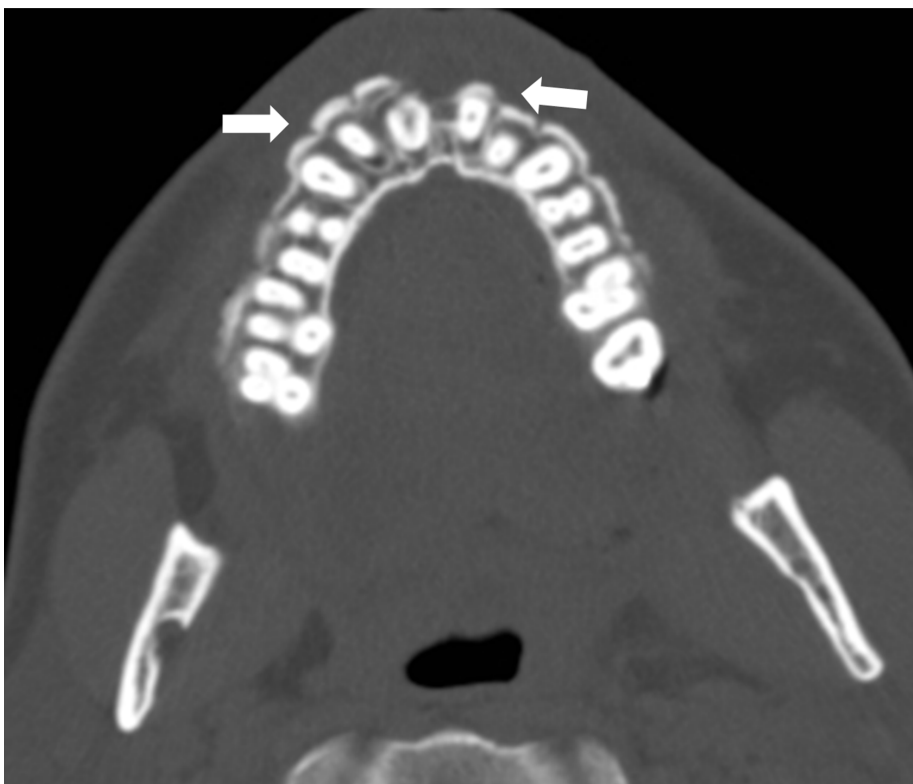


Fig. 9. Alveolar fracture (arrows) sustained by a 45-year-old male after a fall in the sauna.

III Violence

The inclusion criteria were met by 727 patients (aged 15–86 years, mean 37 years), of which 80% (n=583) were male (15–74 years, mean 36 years) and 20% (n=144) female (16–86 years, mean 41 years). Fracture was detected in 74% (n=538; range 15–82 years, mean 38 years) of all patients; 78% (n=454; range 15–74 years, mean 37 years) of all males and 58% (n=84; 16–82 years, mean 42 years) of all females suffered a fracture. The 538 fracture patients had altogether 926 different types of fractures. Multiple separate fractures were sustained by 235 patients (32% of all patients and 44% of those with a fracture, Figures 10 and 11, Table 4).

All patients with fractures and classification of subtypes are presented in Tables 3 and 5-7. Further, the 256 patients with isolated nasal fractures had 185 bilateral and 42 unilateral nasal bone fractures, 42 bilateral and 113 unilateral fractures of the nasal process of the maxilla, and 79 nasal septal fractures. Of the 91 patients with maxillary fractures, six had a bilateral fracture. Only one of the 131 patients with ZMC fractures had a bilateral fracture. All of the 14 NOE fractures were unilateral, and in all but one case (93%), there was an associated nasolacrimal canal fracture.

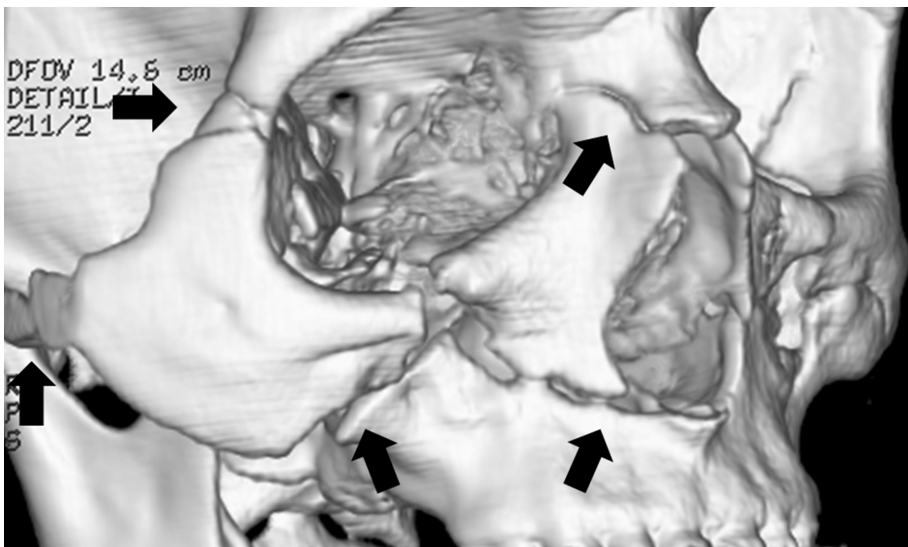


Fig. 10. A 40-year-old male who had been assaulted, resulting in bilateral Le Fort I, II, and III fractures.

LF fractures were sustained by 48 patients (46 males, 2 females; mean 44 years): 10 asymmetric, 22 symmetric, and 16 both asymmetric and symmetric fractures; co-existing types of LF fractures were also frequently detected. Further, there

were five cases with an isolated pterygoid plate fracture without an LF fracture; of these, four patients had, among other fractures, a mandibular subcondylar fracture. Skull base fractures almost always co-existed with facial fractures; of the 31 patients with a skull base fracture, only in one case was no facial fracture detected, whereas 20 had multiple facial fractures.

In the 538 patients with a fracture, 25% (134) had a positive CSS, an absence of paranasal sinus effusions, whereas, among the 189 patients with no fracture, 73% (138) had clear sinuses (Table 8). When further analyzing the CSS, cases in which the imaging was performed over a week after the injury were not included. Also excluded were fractures not next to sinus walls (nasal, lateral and superior walls of the orbit, maxillary alveolar, mandibular, zygomatic arch, and skull base not involving the sinuses). The remaining 25 patients with a false positive CSS, had 21 orbital fractures (12 floor and 9 medial wall), 5 maxillary sinus wall fractures (3 anterior, 1 medial and 1 posterior), 1 ZMC fracture and 1 frontal bone fracture. Furthermore, the CSS was assessed in cases with isolated nasal, isolated zygomatic arch and isolated mandibular fractures: effusions in the sinuses were detected in 45%, 33% and 14%, respectively.

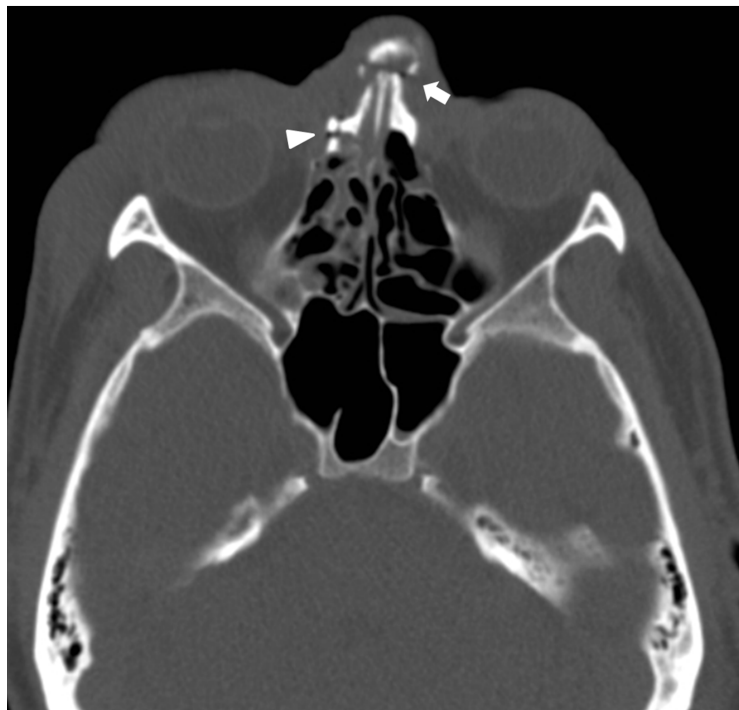


Fig. 11. Nasal bone (arrow) and medial orbital non-blow-out fracture (arrowhead) in a 50-year-old male victim of an assault.

IV Motor vehicle accidents

Included were 374 patients (age 15–80 years, mean 34 years), of which 28% (n=103) were female (15–80 years, mean 36 years) and 72% (n=271) male (15–74 years, mean 33 years) (Figures 12, 13). Of all the 374 facial CT scans, 77.5 % (n=290) were regarded as a part of a trauma protocol; only two patients (0.5 %) underwent an isolated facial CT scan without other imaging studies.

Of all patients, 70% (n=262) had altogether 634 facial or skull base fractures, whilst 30% (n=112) had no fractures. Multiple non-contiguous fractures were detected often: 148 patients (40% of all patients and 56% of those with fracture, Table 4). Only 18% (115 out of 634) were solitary fractures. Further, LF I, II, and III fractures, zygomatic arch fractures, and frontal bone fractures were always accompanied by another fracture.

All fractures and their subcategorization can be seen on Tables 3, 5, 6, and 7. Further, of the 11 NOE fractures, 5 were bilateral and 6 unilateral. All nine isolated zygomatic arch fractures were unilateral. In the 44 patients suffering a ZMC fracture, two were bilateral and 42 unilateral. The masseter muscle seemed to be entrapped by the fractured zygomatic arch in 11 (24 %) cases of the 46 ZMC fractures (44 patients), in 7 (13 %) of the 54 LF III fractures (36 patients), and in one case (11 %) of the 9 isolated zygomatic arch fractures (9 patients). Eighty-two patients had 106 isolated orbital fractures. In only 3 patients (4 %), the isolated orbital fracture extended to the optic canal. However, of the 26 patients with an isolated orbital fracture and a simultaneous skull base fracture, 13 patients (50 %) had skull base fractures which reached the optic canal.

Combinations of different Le Fort fractures were frequent. In addition, Le Fort fractures were always associated with other fractures. Ten patients sustained an isolated pterygoid plate fracture without a LF fracture or with only an opposite side LF fracture. Skull base fractures were sustained by 69 patients; the middle skull base was injured in 91 % of the skull base fracture patients, anterior skull base in 28%, and posterior skull base in 16 %. Of all patients with a skull base fracture, 48 (70 %) were accompanied with multiple facial fractures, and only four skull base fractures were not associated with any facial fracture.

Of all the 262 patients sustaining a fracture, only 23% (n=61) had clear sinuses, whereas in those 112 patients without a fracture, 73% (n=82) had a CSS (p <0.0001, sensitivity 76.7%, specificity 73.2%, positive predictive value 87.0%, negative predictive value 57.3%, Table 8).

Patients sustained more fractures in the group of collisions in comparison with run-off-road accidents, but statistically, the difference was not significant ($p = 0.33$). However, collisions caused multiple fractures more often ($p = 0.017$). Furthermore, LF II and III were proportionally significantly more frequent in collisions than run-off-road accidents ($p = 0.0072$, $p = 0.0119$, respectively). Motorized two-wheeler patients had proportionally significantly more orbital and skull base fractures than patients in a larger vehicle ($p = 0.0022$, $p = 0.0041$, respectively) and altogether larger vehicle patients had more patients with no fractures ($p = 0.0303$). In this study the use of seat belt seemed to have no significant impact on fractures of the face and skull base.

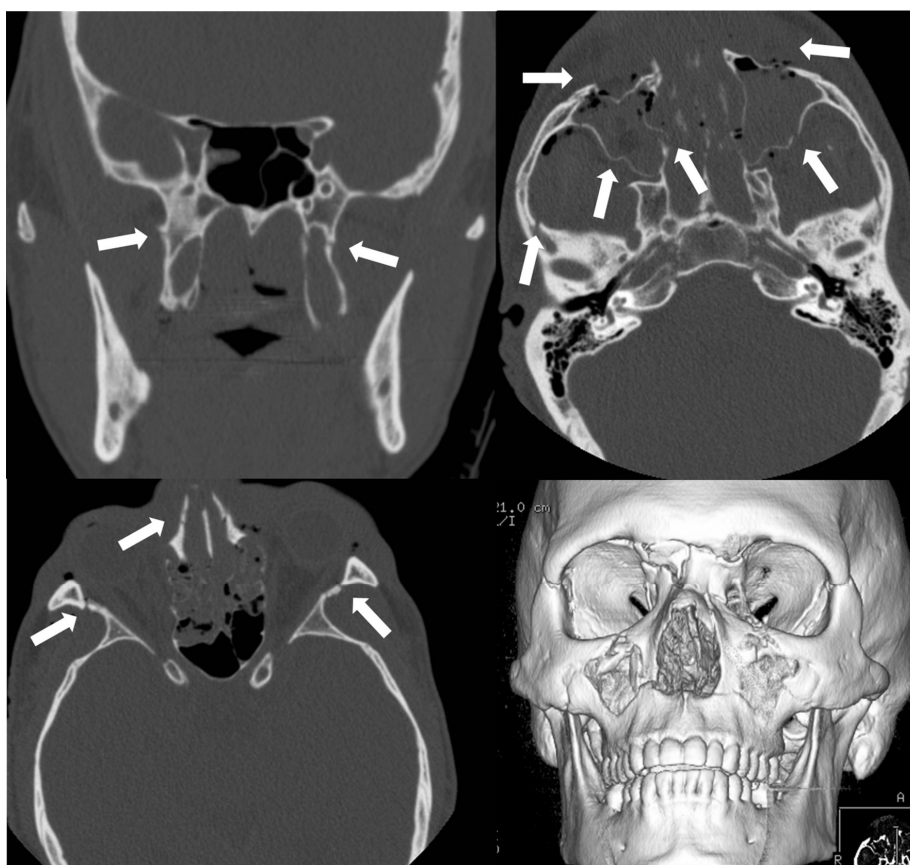


Fig. 12. A 28-year-old male driving a passenger car at 30 km/h collided with a bus. He sustained bilateral Le Fort I, II, and III fractures, nasal bone, and skull base fractures (arrows showing the fractures).

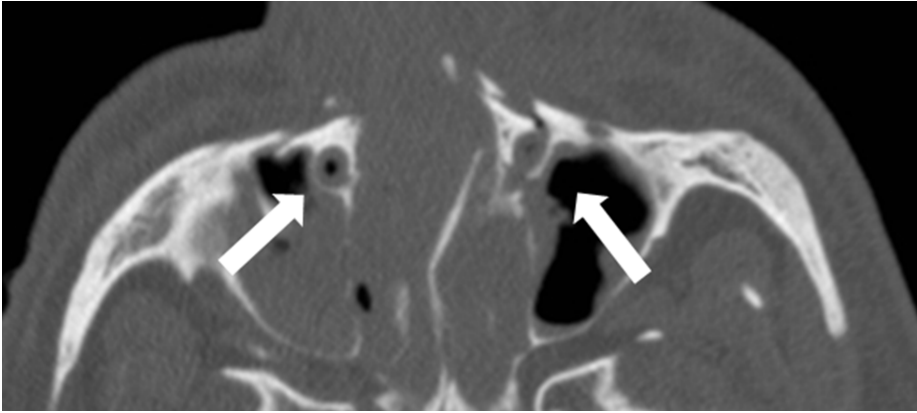


Fig. 13. A 28-year-old male sustained a bilateral naso-orbito-ethmoid fracture (NOE, arrows) after a drive-out accident.

I-IV Falls from heights, Falling accidents, Violence, Motor vehicle accidents

A summary of important findings is provided in Table 9.

Table 3. Number of patients with fractures in each traumatic etiology. Patients with multiple fractures appear more than once.

	FALLS FROM HEIGHTS	FALLS	VIOLENCE	MOTOR VEHICLE ACCIDENTS
Type of fracture	No. of patients with fracture (% of all 155 patients)	No. of patients with fracture (% of all 500 patients)	No. of patients with fracture (% of all 727 patients)	No. of patients with fracture (% of all 374 patients)
Nasal bone	31 (20%)	86 (17%)	256 (35%)	152 (41%)
Orbital	14 (9%)	77 (15%)	192 (26%)	82 (22%)
ZMC	57 (37%)	126 (25%)	131 (18%)	44 (12%)
NOE	5 (3%)	9 (2%)	14 (2%)	11 (3%)
Le Fort I	5 (3%)	19 (4%)	43 (6%)	38 (10%)
Le Fort II	14 (9%)	25 (5%)	34 (5%)	39 (10%)
Le Fort III	13 (8%)	17 (3%)	19 (3%)	36 (10%)
Mandible	24 (15%)	52 (10%)	68 (9%)	53 (14%)
Zygomatic arch	3 (2%)	1 (0.2%)	24 (3%)	9 (2%)
Maxilla other	12 (8%)	46 (9%)	91 (13%)	62 (17%)
Frontal bone	30 (19%)	14 (3%)	18 (2%)	29 (8%)
Skull base	37 (24%)	43 (9%)	31 (4%)	69 (18%)
Other	2 (1%)	-	5 (1%)	10 (3%)
No fracture	37 (24%)	171 (34%)	189 (26%)	112 (30%)

ZMC= zygomatic complex, NOE=naso-orbito-ethmoid

Table 4. Proportions of patients with multiple non-contiguous fractures.

	% of patients with multiple non-contiguous fractures of all patients	% of patients with multiple non-contiguous fractures of all fracture patients
FFH	44	58
Falls	25	37
Violence	32	44
MVA	40	56

FFH= falls from heights, MVA= motor vehicle accidents

Table 5. Distribution of isolated frontal fractures with each trauma method.

Type of isolated frontal fracture	FALLS FROM HEIGHTS, 30 patients	FALLS, 14 patients	VIOLENCE, 18 patients	MOTOR VEHICLE ACCIDENTS, 29 patients
	No. of fractures/ (% of 30 frontal fractures)	No. of fractures/ (% of 14 frontal fractures)	No. of fractures/ (% of 18 frontal fractures)	No. of fractures/ (% of 29 frontal fractures)
Type 1	1(3%)	0 (0%)	4 (22%)	0 (0%)
Type 2	1 (3%)	0 (0%)	4 (22%)	1 (3%)
Type 3	14 (47%)	8 (57%)	5 (28%)	6 (21%)
Type 4	10 (33%)	6 (43%)	3 (17%)	14 (48%)
Type 5	4 (13%)	0 (0%)	2 (11%)	8 (28%)

Table 6. Distribution of isolated orbital fractures with each trauma etiology.

Type of isolated orbital fracture	FALLS FROM HEIGHTS, 14 patients	FALLS, 77 patients	VIOLENCE, 192 patients	MOTOR VEHICLE ACCIDENTS, 82 patients
	No. of fractures/ (of these 18, no. of blow-in or blow-out fractures)	No. of fractures/ (of these 95, no. of blow-in or blow-out fractures)	No. of fractures/ (of these 242, no. of blow-in or blow-out fractures)	No. of fractures/ (of these 106, no. of blow-in or blow-out fractures)
Medial	10 (4)	27 (19)	107 (99)	37 (33)
Inferior	6 (6)	47 (38)	115 (103)	39 (36)
Lateral	0 (0)	8 (2)	6 (3)	11 (5)
Superior	2 (1)	13 (8)	14 (13)	19 (16)
Altogether	18 (11)	95 (67)	242 (218)	106 (90)

Table 7. Number of mandibular fractures and proportion of each fracture type, with each traumatic etiology. * Average number of mandibular fractures per mandibular fracture patient.

Type of mandibular fracture	FALLS FROM HEIGHTS, 24 patients	FALLS, 52 patients	VIOLENCE, 68 patients	MOTOR VEHICLE ACCIDENTS, 53 patients
	No. of fractures/ (% of 48 mandibular fractures)	No. of fractures/ (% of 87 mandibular fractures)	No. of fractures/ (% of 106 mandibular fractures)	No. of fractures/ (% of 96 mandibular fractures)
Symphysis	3 (6%)	6 (7%)	8 (8%)	13 (14%)
Parasymphysis	10 (21%)	11 (13%)	19 (18%)	17 (18%)
Body	8 (17%)	6 (7%)	4 (4%)	7 (7%)
Angular	7 (15%)	4 (5%)	20 (19%)	10 (10%)
Ramus	1 (2%)	0 (0%)	2 (2%)	3 (3%)
Subcondylar	12 (25%)	21 (24%)	29 (27%)	21 (22%)
Condylar	6 (13%)	33 (38%)	10 (9%)	5 (5%)
Coronoid	0 (0%)	5 (6%)	11 (10%)	11 (11%)
Alveolar (isolated)	1 (2%)	1 (1%)	3 (3%)	9 (9%)
Altogether	48 (2.0)*	87(1.7)*	106 (1.6)*	96 (1.8)*

Table 8. Clear sinus sign.

	Patients with fracture; effusions (% of those with fracture)	Patients with fracture; clear sinuses (% of those with fracture)	Patients without fracture; effusions (% of those without fracture)	Patients without fracture; clear sinuses (% of those without fracture)
FFH (155 patients)	95 (80%)	23 (20%)	4 (11%)	33 (89%)
Falls (500 patients)	246 (75%)	83 (25%)	28 (16%)	143 (84%)
Violence (727 patients)	404 (75%)	134 (25%)	51 (27%)	138 (73%)
MVA (374 patients)	201 (77%)	61 (23%)	30 (27%)	82 (73%)

FFH= falls from heights, MVA= motor vehicle accidents

Table 9. Most important findings.

Etiology	Important findings
Falls from heights	<p>Zygomatic complex fractures (37% of all 155 patients) are the most frequent fractures.</p> <p>Injury probability cannot alone be predicted by the height of the fall.</p> <p>Zygomatic arch and nasal bone fractures rarely are solitary fractures, thus indicating the presence of other more severe fractures; multiple non-contiguous fractures are common.</p> <p>An associated injury was seen in 83% of the cases with a facial or skull base fracture.</p>
Falls	<p>Zygomatic complex fractures (25% of all 500 patients) are the most common fractures.</p> <p>Females have two age peaks.</p> <p>Condylar fractures make up 38% of all mandibular fractures.</p>
Violence	<p>Nasal bone fractures (35% of all 727 patients) are the most frequent fractures.</p> <p>Males have significantly more high-energy fracture patterns.</p> <p>Skull base fractures almost always co-exist with facial fractures.</p>
Motor vehicle accidents	<p>Nasal bone fractures (41% of all 374 patients) are the most common fractures.</p> <p>Le Fort, frontal bone, and zygomatic arch fractures are always associated with other fractures.</p> <p>Multiple non-contiguous fractures are frequent.</p>

V Computed tomography of facial fracture fixation

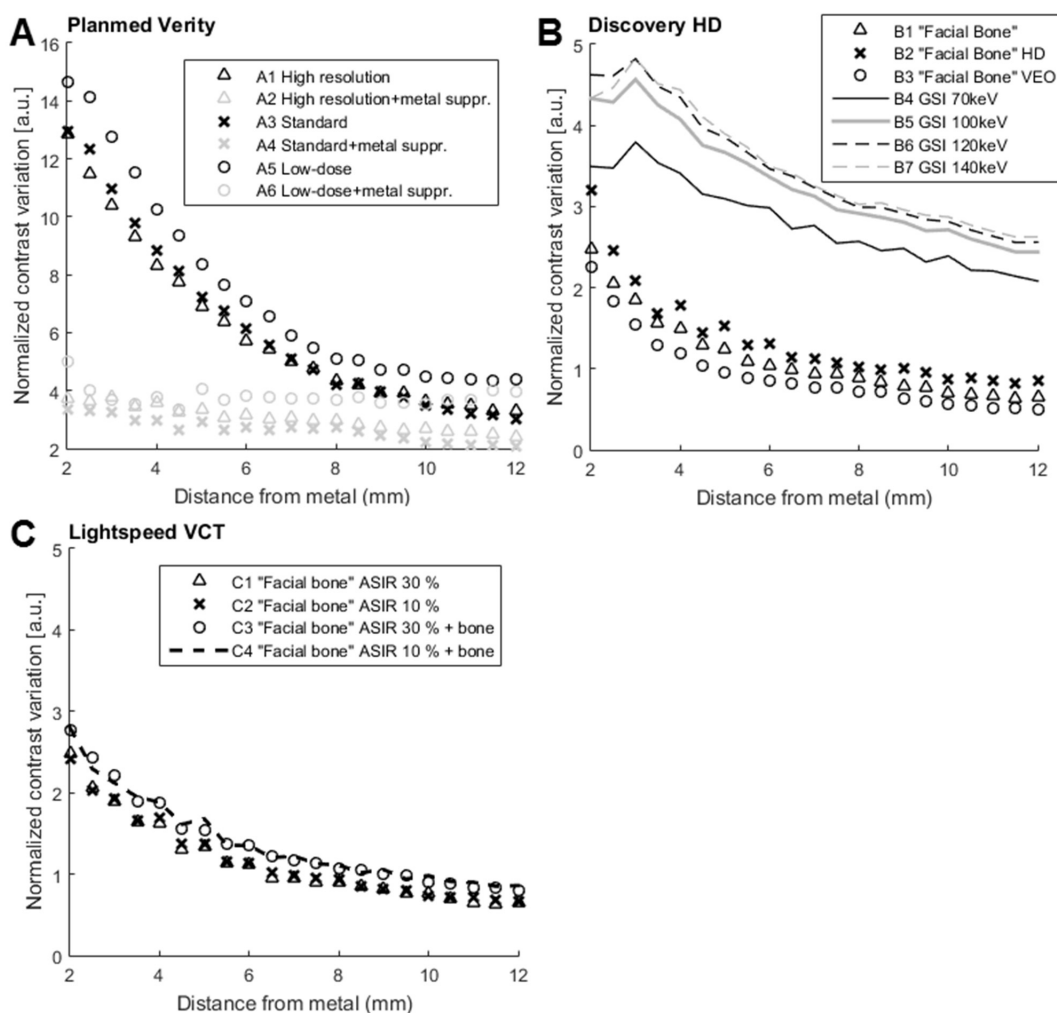
Of the items assessed, overall, both interpreters found that most difficult to assess was the soft tissue next to the screw and plate. The easiest items to assess were the loose screw and both the fracture and bone structure further away from the plate and screw.

With the CBCT, neither interpreter perceived metal suppression as helpful. For the eight different items, the assessment remained almost always either more difficult or the same using metal suppression.

CBCT graphs showed a notable artifact reduction in the soft tissue when metal suppression was enabled, but only little effect from the choice of protocol can be seen. MDCT scanners (data groups B1–3 and C1–4) indicated fairly concise

extent and magnitude behaviors in comparison with each other; however, the GSI images were clearly poorer. Of the GSI images, the 70-keV monochromatic reconstruction (B4) yielded the smallest artifact, while the others (B5–B7) indicated curves similar to one another.

Results from the metal artifact analysis are seen in Figure 14.



Results from the metal artifact analysis: the plotted quantile differences show a typical decreasing streak artifact strength (variation in intensity), as the distance from the metal increases. Enabling metal suppression in Planned Verity® (gray points in a) decreased the apparent artifact effect. GE scanner protocols (b, c) without the gemstone spectral imaging (GSI) data resulted in a similar behavior in both the magnitude and extent of the artifact; a has a different scale compared with b and c. ASiR, adaptive statistical iterative reconstruction; VEO, model-based iterative reconstruction technique.

Figure 14. Results from the metal artifact analysis. *Reprinted and adapted with permission from Peltola EM, Mäkelä T, Haapamäki V, Suomalainen A, Leikola J, Koskinen SK, Kortessniemi M, Koivikko MP. CT of facial fracture fixation: an experimental study of artefact reducing methods. Dentomaxillofacial Radiology 2017; 46: 20160261. doi 10.1259/dmfr.20160261*

DISCUSSION

General

MDCT is the cornerstone of modern emergency radiology. It can be used to detect and characterize injuries in the whole body, from intracranial and facial injuries to trauma of the extremities. Nondisplaced fractures as well as 3D morphology can be visualized, improving the detection of complex fractures. MDCT enables high-quality MPR and isotropic viewing (Rydberg et al. 2000). Two-dimensional images are more sensitive than 3D images, but both are needed to achieve an optimal treatment plan (Patil et al. 2014). All of these improve the diagnostic power of this imaging modality, therefore benefiting the injured patients. With the use of whole-body spiral CT, life-threatening trauma can be detected with good specificity and sensitivity, resulting in a major impact on early treatment (Linsenmaier et al. 2002). Further, CT has a significant role in assessing sinonasal diseases, osteomeatal complex anatomy, and bony changes, e.g. bone erosion or destruction, thereby resulting in better planning of the patient's treatment (Kandukuri and Phatak 2016).

MDCT is a widely used, well-accepted, and straightforward imaging method. After trauma, the restoration of the face involves both accurate clinical and radiological evaluation to effectively plan the management of these injuries (Ricketts et al. 2016). In other words, to achieve an accurate diagnosis, adequate imaging is essential. However, it is important that each patient's clinical findings guide the use of CT. Therefore, the radiologist must be an active part of the trauma team (Linsenmaier et al. 2002). Previously, physical examination was the primary method in the evaluation of a trauma patient. Recently, the diagnosis of facial fractures has been overly based on imaging studies. For instance, the absence of dental malocclusion and tenderness of the mandible or the nasal bone indicate that mandibular and nasal fractures are unlikely. Further, patients without a physical examination finding for a particular facial fracture did not need surgery for that injury. These findings may be helpful in reducing expensive imaging and unnecessary radiation in patients with facial injury without facial fractures (Timashpolsky et al. 2016). However, significant swelling of the face, polytrauma, patient cooperation, and limited physical examination can result in missing major findings. Thus, accurate interpretation and communication of the CT findings are critical in successful management of the patient (Ludi et al. 2016).

Trauma to the head and neck is a major cause of morbidity and mortality; rapid physical and radiological evaluations are needed. It is important that the radiologist recommends optimal imaging protocols for evaluation of the region of interest and identifies the different bone and soft tissue injury patterns in these regions. The radiologist must not only be able to interpret the acute imaging findings but also needs to have thorough knowledge of potential short- and long-term complications (Sung et al. 2012). Further, it is important that radiologists note fractures requiring surgical management as well as identify incidental findings that may affect the patient's treatment (Sohns et al. 2013).

I-IV Falls from heights, Falling accidents, Violence, Motor vehicle accidents

The etiologies, demographics, and fracture patterns differ between countries and time periods. These differences arise from cultural, societal, environmental, and legislative divergence (Lee 2012). Worldwide, the most important cause of maxillofacial injuries is road traffic crashes, with the exception of Europe and North America, where falls and assaults have become more important (Boffano et al. 2014 and 2015 b). This concurs with our findings that violence followed by falls are the most common etiologies. The differences may be due to more strict traffic laws and a consequent decrease in road traffic accidents on these continents. Further, aging of the population, especially in Europe, may play a part in the increase of falls. In addition, the strict work legislation in Europe may also have a role in the change (Boffano et al. 2015 b). Similarly, Rallis et al. (2015) concluded that obligatory seatbelt use and penalizing driving under the influence of alcohol and speeding have led to a lower incidence of fractures caused by road traffic accidents. In developed countries, the incidence of facial fractures caused by violence is increasing (Rallis 2015). Alcohol consumption has a marked role in assault-related fractures. There is a need for national prevention programs to prevent the abuse of alcohol, and thus, to reduce assault-related facial fractures (Boffano et al. 2015 a). Martinez et al. (2014) noticed some major differences in maxillofacial injuries in the last two decades at their institution, namely a decrease in assault-related injuries in younger people and an increase in falls in the elderly. Further, there was a remarkable increase in older patients sustaining maxillofacial injuries (Martinez et al. 2014). Overall, men are more frequently involved in these injuries (Boffano et al. 2014 and 2015 b). Similarly, in our studies (I, III, and IV) there were more male than female patients. When taking into account only the patients with a fracture, males predominated in all our studies (I-IV). This was most distinctive in falls from heights, followed

closely by victims of violence. In falls, the difference between genders was the smallest. Further, these findings are similar to earlier studies in which younger drivers, especially males, are overrepresented (Peden et al. 2004, Elvik 2010); the difference between the mortality rates between genders may be related to risky behavior and exposure (Peden et al. 2004). Overall, the fracture type is dependent on the velocity and mass of the wounding object. With the changing lifestyle, also a change in fracture patterns can be seen (Patil et al. 2014).

Facial fractures are often associated with trauma to the skull, brain, cervical spine, and soft tissues (Patel et al. 2012). Allareddy et al. (2011) noted in their study that the most common concomitant traumas with facial injuries were open wounds of the trunk, neck, and head, followed by fractures of the upper limbs, skull, and other fractures, and finally intracranial injuries. We assessed concomitant injuries in Study I, in which patients with facial or skull base fractures most often had brain injury followed by upper extremity, spine, and thorax injuries. Of patients without facial or skull base fractures, the most frequently associated injuries were the same, but in a slightly different order: brain injuries followed by thorax, upper extremity, and spine injuries. Snell et al. (2014) observed that patients sustaining craniofacial injuries after a high-energy trauma should raise high suspicion of a brain injury even in the absence of loss of consciousness, visible neurocranial fracture, or intracranial lesions, concluding that a neuropsychologist should be a member of the multidisciplinary team. Thus, patients sustaining maxillofacial trauma with or without facial fractures are at risk of traumatic brain injury (acute or delayed), and therefore, all patients should have radiological assessment with observation and follow-up (Rajandram et al. 2014, Zandi and Hoseini 2013). With older patients (50 years and older), the incidence of concomitant traumatic head injuries is high. There is a need for adequate prevention measures and appropriate maxillofacial surgical teams to take care of the injuries of older patients (Martinez et al. 2014). Patients who have had loss of consciousness, are intubated, intoxicated, have GCS 8 or less, ISS 16 or more, and have visible findings of facial injuries have a statistically increased risk for facial fracture. These patients may benefit from adding maxillofacial CT to the conventional trauma scanning protocol. However, with patients sustaining multisystem trauma, if there are no facial physical examination findings, facial fractures requiring surgery can be excluded. In this situation, the maxillofacial CT can be omitted, with the benefit of cost containment and possibly better workflow (Whitesell et al. 2015).

The frontal sinus (over 84-fold increase) and LF II (nearly 27-fold increase) fractures were the strongest predictors of cranial trauma in patients with maxillofacial injuries (Zandi and Hoseini 2013). Also LF I, zygomatic, nasal,

mandibular, and dentoalveolar fractures were among the other predictors of cranial trauma (odd ratios between 2 and 8). However, LF III and NOE fractures seemed not to increase the risk of head injuries. This surprising finding might be due to the few NOE and LF III fracture cases in the study by Zandi and Hoseini (2013). However, the results of previous studies assessing the relationship between head and facial injuries are conflicting. Zhou et al. (2015), for instance, found that mandibular fractures, especially condylar fractures, reduced the incidence of traumatic head injury. By contrast, the risk of head injury increased in patients with pan-facial fractures (Zhou et al. 2015). Further, Bellamy et al. (2013) concluded that both LF II and III fractures were associated with serious intracranial trauma, even when no alterations in consciousness occurred. LF II fractures were associated with elevated mortality (Bellamy et al. 2013). Chu et al. (2016) noted that multiple mandibular fractures were inversely correlated with cervical spine trauma and directly correlated with concomitant injury under the head and neck; the inverse correlation might be due to energy dissipating in the mandible with multiple fractures, thus protecting the cervical spine. However, the associations in the pattern of mandibular fractures and simultaneous cervical spine injury were different between children and adults. This has implications in the treatment and imaging of injured patients (Chu et al. 2016). Further, Avery et al. (2011) found that fractures of the upper face (superior orbit and forehead) were associated with an increased probability of lower cervical fractures and intracranial trauma. Unilateral fractures of the mandible were seen in conjunction with upper cervical spine trauma. Unilateral fractures of the midface (nasal, orbital, maxillary, and zygomatic regions) were associated with multiple intracranial injuries and basilar skull fractures. Furthermore, severe bilateral midface trauma was associated with severe skull base fractures or death. These predictable associations should lead the radiologist to recommend additional imaging in patients undergoing facial CT (Avery et al. 2011). In our studies, we did not assess the type of facial fracture with the associated trauma, which would be an interesting focus for future research.

Falling height has been shown to predict the severity of injuries and the outcome (Velmahos et al. 1997). Similarly, in our data, there was a slight increase in the number and severity of fractures with increasing height. However, there was considerable overlap in heights, and thus, falling height cannot be the only predictor of injury probability. Xia et al. (2012) concluded that along with height the ground-contact posture and the nature of the ground itself (soft or hard) were defining features. The reason behind the fall was associated with the falling height: homicides cases were from 0-20 m, accidental cases mostly under 10 m. The latter occurred mostly at construction sites during working hours, as suicides mainly occurred at home or out-of-the-way sites (Xia et al. 2012). In

our material, we did not divide the falls into subgroups by these factors, but included all falls from heights during the time studied. This is a small deficiency that had it been covered would have brought even more information.

Falls often cause facial trauma. Falling is frequently associated with morbidity, expensive hospital stay, psychological problems, and even mortality. Falls affect all age groups and can be divided into falls from heights, falls on stairs, slips, and stumbling (Zandi et al. 2011). Zandi et al. (2011) had further divided falls into vertical falls from various heights (standing or greater heights, forward, backward, to the side) and stumblings, where the direction is forward-downward. They found that incidence, rate and pattern of bone fractures, age distribution, frequency, and type of associated injuries caused by stumbling was significantly different from injuries due to other types of falls. Older people have different patterns of facial trauma than younger patients. Falls are the major cause for facial fractures in older persons, especially elderly females. Thus, it is important to examine these patients thoroughly even in a low-energy mechanism setting (Atisha et al. 2016). Isolated orbital fractures are a frequent finding in the aged, and thus, when an elderly patient presents signs of midfacial trauma, one should strongly suspect an orbital blow-out (Toivari et al. 2014).

The severity and site of fracture are influenced not only by the age of the patient but also by the mechanism of the fall. Falls on level floor (stumbling, slipping, tripping) are the most significant cause of facial fractures, females being most affected in the elderly. These injuries are more severe when the patient has fallen without an efficacious protection reflex to attenuate the impact with the ground. The general prevalence of maxillofacial fractures in falls was the middle third, however, with injuries caused by loss of consciousness, the lower third was more frequently affected. Falls from heights, especially over 3 m, caused the most severe maxillofacial and concomitant injuries (Roccia et al. 2014). Further, in our studies we noted more multiple non-contiguous fractures in the fall-from-height group than in the falls group or the violence group. MVA patients had also many multiple fractures like the fall-from-height patients. This is logical and coherent with the energy of the impact. However, it is important to notice that even in the falls group, 25% had multiple non-contiguous fractures, implying that the radiologist should continue to search for more injuries after detecting one.

In our material of frontal fracture patients, in the groups of falls from heights, falls, and MVA, only 6%, 0%, and 3%, respectively, had frontal fracture types 1 and 2 in comparison with 44% in the violence group. This is somewhat surprising, as according to smaller energy in the mechanism of trauma, one

would assume that falls would result more in type 1 and 2 frontal fractures than the more severe types. However, it is logical that falls from heights and MVAs result mostly in types 3-5 due to higher impact force. Further, type 5 fractures were most frequent in the MVA group, being consistent with the method and force of MVAs.

A seatbelt alone or a seatbelt and an airbag decreased facial fractures in MVA. However, an airbag alone did not markedly diminish the risk of facial fracture. Thus, the use of seatbelts together with airbags is important for the prevention of facial fractures with MVA (Hwang and Kim 2015). In Study IV, patients using seatbelts had less frequently skull base or facial fractures compared with non-users, but the difference was not significant. Surprisingly, there were more fractures in the group using seatbelts than in those who did not. Seatbelt users also had more high-energy fractures: LF, skull base, and frontal fractures. However, based on various studies, it is clearly evident that restraining systems decrease mortality (Peden et al. 2014) and also as previously mentioned, decrease facial trauma (Hwang and Kim 2015, Mouzakes et al. 2001, Williams et al. 2008). Helmets and seatbelts can be used to prevent the incidence of head injury (Zhou et al. 2015). Therefore, our findings may be due to the fact that of the victims not using seatbelts some die instantaneously or have such immense trauma that they are not imaged for facial fractures. A limitation in our study was that in many of our cases the use of restraining systems was not reported. Moreover, because of the small number of cases, chance may have affected the results.

According to Shin et al. (2013), of blow-out fractures, medial orbital was most often involved, followed by floor and inferomedial wall. The most common cause for blow-out fractures were assaults, followed by falls/slips and traffic accidents. Blow-out fractures may cause hyphema, diplopia, and extraocular movement limitation (Shin et al. 2013). The most common blow-out fractures in Studies I-IV were those of the orbital floor, followed by medial wall, superior wall, and lateral wall. This was also the order with all orbital fractures in Studies II-IV, while Study I had more medial than floor fractures. The medial wall and floor of the orbit are probably most frequently involved because they are thinner structures than the superior and lateral walls. According to Zhou et al. (2014), there is a high incidence of ocular trauma in patients who sustain maxillofacial fractures. Age is strongly related; under 12-year-olds had a low risk, whereas 30- to 39-year-olds had a high risk for ocular injury. Patients with a MVA etiology were most affected. Midfacial fractures, especially multiple midfacial fractures, increased the risk for ocular trauma. However, mandibular fractures, especially multiple mandibular fractures, reduced the risk (Zhou et al. 2014). In Study IV,

we assessed whether the isolated orbital fractures extended to the optic canal; this was the case in 4% of patients. Further, when taking into account patients with an isolated orbital fracture and a simultaneous skull base fracture, 50% of these patients had a skull base fracture extending to the optic canal. Thus, when clinically needed, we concur with Zhou et al. (2014) that an ophthalmologist should take part in the diagnosis of ocular trauma in patients with maxillofacial fractures.

In Studies I-IV, LF fractures were frequently combinations. This is in accord with other studies, in which the majority of LF fractures are variants of classical LF fractures (Bredell and Grätz 2011, Patil et al. 2014). The LF I pattern was higher with high-velocity trauma than with low-velocity trauma (Roumeliotis et al. 2015). After blunt trauma, pterygoid plate fractures seen in CT images usually suggest an underlying LF fracture. However, when the imaging study extends only to the skull base, associated fractures, e.g. mandibular fractures, may be missed; CT of the mandible may be indicated when isolated pterygoid plate fractures are detected (Truong et al. 2014). Likewise, in Studies I-IV only a few isolated pterygoid fractures were found. Garg et al. (2015) reported that about two-thirds of pterygoid fractures are related to LF fractures. The remaining third is often caused by calvarial, sphenotemporal buttress, ZMC, and displaced mandibular fractures; these should be kept in mind when assessing the imaging of facial injury patients (Garg et al. 2015). Similarly, in Study III, only a few pterygoid plate fractures without an LF fracture were observed. Further, 80% of these isolated pterygoid plate fractures were associated with subcondylar fractures.

Skull base fractures often occur with complex facial fractures and serious complications, e.g. vascular or cranial nerve trauma, meningitis, or cerebrospinal fluid leak. The detection of these often subtle fractures is critical to prevent complications or enable their early management (Bobinski et al. 2016). Similarly, in our material, skull base fractures were very frequently associated with at least one facial fracture (range 89–97%). Thus, when detecting a skull base fracture, it is crucial that the radiologist carefully searches for facial fractures.

Clear sinus sign, i.e. lack of effusion in the sinuses on CT scans, has been thought to rule out essentially all facial fractures with the exception of those fractures non-contiguous to the paranasal walls, e.g. nasal bones and zygomatic arch (Lambert et al. 1997, Grechushkin et al. 2016). Lambert et al. (1997) found no patients with paranasal sinus wall fracture and clear sinuses. When evaluating the CSS in Studies II and III, we excluded fractures not involving the sinus walls, and further, excluded scans taken more than one week after trauma. After these exclusions, we had 20 patients (6% of all those with a fracture) and

25 patients (5% of all those with a fracture), respectively, with clear sinuses and a paranasal wall fracture. In Study II, we also took into account the level of displacement of the fractures in the 20 patients, with about half of the fractures being displaced more than the thickness of the bone. In Study IV, there were no clear sinuses with NOE, frontal, LF, or isolated pterygoid plate fractures. The specificity of the effusions was quite low in Studies I-IV; 11-27% of patients without fractures had effusions. No marked difference existed between different etiologies of trauma and CSS. Thus, we concluded that the CSS is an important aid for radiologists, but less reliable than previously thought.

Often craniofacial and skull base trauma are overlooked while treating more life-threatening injuries. However, unnoticed complex skull base and craniofacial fractures, cerebrospinal fluid fistulae, and cranial nerve trauma may result in diplopia, blindness, deafness, facial paralysis, or meningitis. Thus, early assessment and management of these injuries should decrease mortality and morbidity (Katzen et al. 2003). Precise categorization of facial fractures and identification of associated complications by the radiologist enables accurate surgical care and an enhanced clinical outcome (Winegar et al. 2013). During the last 50 years surgeons have been moving away from conservative treatment, embracing the open reduction internal fixation (ORIF) approach (Rallis et al. 2015). For restoration of the form and function of the mandible, ORIF is increasingly favored. Therefore, management decisions are relying increasingly more on MDCT. For radiologists to be able to pinpoint clinically important information, they must understand the main issues of the surgeons' decision-making process such as biomechanics of the mandible. Understanding treatment of complications is also necessary (Dreizin et al. 2016).

V Computed tomography of facial fracture fixation

For preoperative evaluation of facial trauma, high-resolution MDCT with multiplanar reformats and 3D post-processing often provides the details needed (Lo Casto et al. 2012).

Nowadays, MDCT is often used for evaluating progress of surgical fusion and fracture healing even in the presence of hardware (Geier and El-Khoury 2006, Ohashi et al. 2005). This is possible due to the decrease in hardware artifacts with MDCT and improved reconstruction algorithms. The details of a protocol have to be tailored according to the specific model and make of a CT scanner (Geijer and El-Khoury 2006). Previously, surgical hardware caused streak artifacts, rendering assessment of CT images difficult. However, soft tissue

evaluation near large metal implants is still challenging (Geier and El-Khoury 2006), as was also the case in our study.

For clinical cases, metal kernels were not found to substantially improve accuracy (Huang et al. 2016). The authors concluded that of the commercial artifact reduction methods investigated, for all-purpose CT simulation imaging, Philips Healthcare's O-MAR was the most consistent candidate; GE Healthcare's monochromatic gemstone spectral imaging GSI with metal artifact reduction software (MARS) should be used with caution for larger implants, titanium implants, and implants near heterogeneities because it could distort the shape and size of implants and increase calculation mistakes (Huang et al. 2016). Further, the MAR algorithm on CBCT did not improve the diagnosis of peri-implant fenestrations and dehiscences (de-Azevedo-Vaz et al. 2016). Similarly, we noted that metal suppression with CBCT did not give an additional benefit; in fact, this technique made image evaluation more difficult because it produced gray areas. These gray areas were challenging to identify as an artifact and made the interpretation of images unreliable. After noticing this, we immediately disabled the metal reduction option from our clinical CBCT protocols. We thus do not recommend a non-iterative CBCT with or without a metal reduction algorithm for postoperative facial imaging. However, IR methods (ASiR and VEO) in MDCT performed well.

In comparison with MDCT, CBCT produces lower-quality images regarding soft tissues. However, MDCT images are affected more by beam-hardening artifacts caused by implants and dental-care materials than CBCT images (Luminati and Tagliafico 2014). Veldhoen et al. (2016) concluded that CBCT imaging provided better image quality with less noise at lower doses. The performance of CBCT and MDCT was similar at higher exposure settings. The CBCT is very suitable for dental imaging due to its high resolution. According to Veldhoen et al., MDCT should be preferred instead of CBCT when soft tissue assessment is important, e.g. in oncologic imaging (Veldhoen et al. 2016). However, Jeong et al. (2012) found out that for imaging of the mandible the effective dose of MDCT did not significantly differ from that of CBCT. The dose levels varied significantly among different CBCT devices. By using low-dose techniques, the effective dose of MDCT could be noticeably decreased (Jeong et al. 2012). Brisco et al. (2014) concluded that the dose of radiation from CBCT was significantly lower than the lowest radiation dose from MDCT when discussing effective dose and dose to the eye lens.

Overall, CBCT is a simple and efficient method to scan sinuses, e.g. to assess sinusitis or to be guide surgical intervention, with marked radiation dose reduction

compared with conventional and low-dose MDCT. However, because of its low contrast resolution for soft tissue, conventional CT is recommended for more advanced sinus disease assessment (Abduwani 2016). This is in line with our findings. Further, along with conventional CT, MRI is an appropriate method for assessing soft tissues (EC 2012).

In conclusion, the significance of metal artifacts is somewhat subjective, as interpreters evaluated different imaging methods slightly differently. However, the worst and best are apparent. MDCT with ASiR filtering offers good image quality with fast image volume reconstruction and is recommended in postoperative maxillofacial imaging.

Limitations

Studies I-IV are based on a large material of consecutive MDCT scans of the face with various traumatic etiologies. Despite our large material, our study has several limitations. In Studies I-IV, imaging was done with a non-contrast four-section multislice CT. The resolution was not as good as with those 64-section CT scanners used currently. Thus, some minor fractures may have gone undetected, and in some instances, this might also have had a clinical impact. Our study took place at the Töölö Trauma Center, the leading level 1 trauma center in Finland, serving a population of about 1.3 million. Only the more difficult cases are referred to Töölö, and thus, the material does not include most of the minor facial trauma, with the result that the more severe types of fractures may be overrepresented in our material. Further, unfortunately, some patients with facial trauma die at the place of trauma or are so badly injured that they are not imaged for facial fractures, and are thus not included in our material. Another limitation is that we retrieved the etiology based on MDCT requests and not from medical reports. Often facial MDCTs are taken quite close to the time of the accident, and sometimes this first-hand knowledge later changes or becomes more precise. For example, the falling height can be a rough estimate or information about the use of restraints in MVA may be missing.

In Study V, we used an animal-derived phantom, resulting in different scanning slice orientation and anatomy than in humans. Regarding blinding of the datasets, the experienced radiologists evaluating the scans probably recognized which scans resulted from which device/protocol. Further, we used preset monochromatic images in contrast to clinical use, where radiologists may select the energy level and slice thickness to obtain the best image quality.

CONCLUSIONS

I Falls from heights

Zygomatic complex fractures are the most frequent fractures. Zygomatic arch and nasal bone fractures seldom occur alone, usually indicating the presence of more severe fractures in falls from heights. Injury probability cannot alone be predicted by the height of the fall because of considerable overlap in the heights. However, patients with frontal bone, mandibular, or LF II or III fractures have typically fallen from higher than patients with other maxillofacial fractures. Skull base fractures are a frequent finding with LF II, III, and frontal bone fractures, all of which are found almost solely in males. Multiple non-contiguous fractures are common. In a fall-from-height injury, clear sinus sign is a useful means of assessing midfacial trauma, bearing in mind that 11% of patients without fractures had effusions. An associated injury was seen in 83% of the cases with a facial or skull base fracture.

II Falling accidents

Facial fractures caused by falls are common. Zygomatic complex fractures are predominant; LF fractures often present as asymmetric or combined patterns. Males have more fractures than females. The highest age peak in males is in the age group 50-55 years; in females, there are two peaks: 50-55 years and 80-85 years. Condylar fractures make up 38% of all mandibular fractures. In falling accidents, several patients have fractures involving the sinus walls without paranasal sinus effusions; thus, a clear sinus sign might be less reliable than previously thought.

III Violence

Violence is a usual cause of facial trauma. Orbital and nasal fractures are the most common fractures. Males are more frequently involved than females; they are younger, sustain fractures more often, and significantly more often have high-energy fracture patterns. LF fractures frequently present as asymmetric or unilateral, and are frequently associated with other, clinically significant fractures. Skull base fractures almost always co-exist with facial fractures. Up to 25% of patients with fractures do not have sinus effusions.

IV Motor vehicle accidents

Nasal fractures are the most frequent fractures, followed by orbital, skull base, and maxillary fractures. LF, frontal bone, and zygomatic arch fractures are always associated with other fractures. Fractures often co-occur, as 39% of all patients had multiple facial or skull base fractures. In the two-wheeled group, only 15% of patients do not have facial or skull base fractures. Low-energy sentinel injuries and negative clear sinus sign can be trusted as indications of undetected trauma in MVA patients.

V Computed tomography of facial fracture fixation

For postoperative maxillofacial imaging, CBCT with or without metal artifact reduction algorithm was suboptimal, and thus, is not recommended. In MDCT, iterative reconstruction methods ASiR and VEO performed well. MDCT with ASiR, offering good image quality with fast image volume reconstruction, is the current method of choice in postoperative maxillofacial imaging.

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